TRANSITIONING URBAN ORGANICS: FROM WASTE MANAGEMENT TO INTEGRATED RESOURCE PLANNING USING INSIGHTS FROM THE WATER SECTOR

by

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Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy in Sustainable Futures

June 2023

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Andrea Turner, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy (Sustainable Futures) at the Institute for Sustainable Futures, University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

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Date: 16/06/2023

ACKNOWLEDGMENTS

Thank you to my supervisors Professor Damien Giurco and Associate Professor Simon Fane for all their professional and emotional support and to help me finally get over the finish line after all these years. I also acknowledge the support of Kathleen Austin-Gifford who provided proof reading and editing assistance in the final months and Sarah Craske who held my hand sorting the references and formatting through the last few weeks.

Thank you to the industry funders of each of the case studies, my fellow researchers involved in the case studies and ISF colleagues and friends who checked in with me along the way.

Finally, thank you to my partner Craig and daughter Abbie for putting up with me and my sister Jacky who encouraged me to push myself and then tried every trick in the book to keep me going.

This thesis is dedicated to my mum and dad who gave me every opportunity to fulfil my potential and my big sister Hilary who chose another path. I miss you all…

COVID-19 IMPACTS

COVID-19 affected the research in three main ways. Firstly, the last Sydney-based case study, with the Inner West Council, was delayed by nearly a year. This included the scope associated with options and decision-making being modified and the final report not being released to the public. Secondly the delay in the last case study and shift in scope had a knock on effect in terms of the write-up and timing of this thesis, which spanned significant changes in policy. This included the release of the latest NSW 20-year waste strategy and resulted in the need to shift the focus of the thesis and re-write several sections. Finally, as with many students, COVID-19 and the lock-downs had a personal impact which affected and slowed the write-up stage of this thesis.

FORMAT OF THESIS & LIST OF PUBLICATIONS

This thesis stands on its own whilst building on a series of peer reviewed industry technical research reports related to the Sydney-based case studies (by the thesis author) which are provided in the appendices for information.

My specific contributions to each of the Sydney-based case studies listed below are outlined in Section 5.0 of this thesis.

Turner, A., Fam, D., Madden, B and Liu, A. (2017). *Pyrmont-Ultimo Precinct (PUP) Scale Organics Management Scoping Study*. Prepared for Sydney Water Corporation and the NSW Environment Protection Authority by the Institute for Sustainable Futures, University of Technology Sydney https://opus.lib.uts.edu.au/handle/10453/118506

Turner, A., Fam, D., McLean, L., Zaporoshenko, M., Halliday, D., Buman, M., Lupis, M., & Kalkanas, A. (2018). *Central Park Precinct Organics Management Feasibility Study.* Prepared for the City of Sydney and Flow Systems by the Institute for Sustainable Futures, University of Technology Sydney https://opus.lib.uts.edu.au/handle/10453/130784

Turner, A., Fam, D., Jacobs, B., & Jazbec, M. (2019). *Organix19: Organics Waste Management in a Circular Economy*. Institute for Sustainable Futures https://opus.lib.uts.edu.au/handle/10453/147622

Jazbec, M., Turner, A., Madden, B., & Fam, D. (2020a). *Organics Revolution: Planning for 2036 and beyond*. Prepared for Inner West Council, Institute for Sustainable Futures, University of Technology Sydney.

In addition, Section 3.0 draws on:

Turner, A., and Fane, S. (2023). Integrated Resource Planning: a Systems Approach to Utility Planning. *Journal of Systems Thinking, 3 (3)*: 1-13 Cabrera Research Lab
DOI: 10.54120/jost.0000044
https://www.scienceopen.com/hosted-document?doi=10.54120/jost.0000044

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ABBREVIATIONS

ABS	Australian Bureau of Statistics
AD	Anaerobic digester (or digestion)
AWT	Alternative waste treatment
CBA	Cost benefit analysis
C&D	Construction & demolition
CFT	Context focused thinking
C&I	Commercial & industrial
CP	Central Park
DEFRA	Department for Environment Food and Rural Affairs, UK
EMF	Ellen MacArthur Foundation
FOG	Fats, oils & grease
FOGO	Food organics garden organics
FW	Food waste
GHG	Greenhouse gases
HR	High-rise
IWC	Inner West Council
IRP	Integrated resource planning
LCA	Life cycle analysis/assessment
LCC	Life cycle costing
LGA	Local Government Area
LTS	Large technical system(s)
MBT	Mechanical biological treatment
MCDA/M	Multi-criteria decision analysis/making
MLP	Multi-level perspective
MSW	Municipal Solid Waste
MUD	Multi unit dwelling(s)
PESTLE	Political, economic, social, technological, legal and environmental
PUP	Pyrmont-Ultimo Precinct
NSW EPA	NSW Environment Protection Authority
OEH	Office of Environment and Heritage
SDG	Sustainable Development Goal(s)
SSD	Strategic sustainable development
SNM	Strategic niche management

STRN	Sustainable Transitions Research Network
SUD	Single unit dwelling(s)
SWC	Sydney Water Corporation
TBL	Triple bottom line
UOW	Urban organic waste
WARR	Waste Avoidance and Resource Recovery
WRAP	Waste and Resources Action Program
WWTP	Wastewater treatment plan

ABSTRACT

Urban organic waste (UOW) is a pervasive issue causing economic, social and environmental impacts. While Australian policies now require food waste to be halved and organics to be separated at source by 2030, significant quantities are still generated and prescriptive large-scale technical solutions are advocated. These solutions are not necessarily the most sustainable nor context appropriate and are often at odds with the waste (management) hierarchy and circular economy.

This research has identified gaps in existing waste management planning and decision-making approaches. Specifically, with respect to commercial and industrial sources and their unique UOW characteristics, which go beyond the traditional residential organic waste streams managed by councils. This necessitates a more structured approach to managing UOW. Integrated Resource Planning (IRP), a practical decision-making approach used in water and energy essential services for decades, to prioritise avoidance and consider a range of socio-technical context appropriate solutions, offers promise for UOW but has had limited application to date.

This thesis investigated:

- at a theoretical level – how IRP, augmented with systems thinking and sustainability transitions, can fill many of the identified waste management planning gaps for UOW, through a comparative meta-analysis of IRP’s use between water and UOW
- at a detailed empirical level – specific knowledge gaps, identified by the literature and industry leaders, on the types and quantities of UOW at various scales and potential innovative context-appropriate solutions available in response, through Sydney-based nested case studies
- at a practical level – how based on the case study experience, the combination of IRP, systems thinking and sustainability transitions methods, can improve the IRP approach, especially for UOW application

The research has demonstrated the benefits of the augmented IRP approach developed from system boundary definition, stakeholder analysis and broad context assessment to the use of detailed disaggregation and visual mapping to aid in broad options generation and assessment. It has demonstrated the use of the concepts and methods at various scales and

revealed key insights despite the significantly fragmented management of UOW and lack of data.

This thesis finds that the major growth in mixed use building/precinct scale developments in Sydney and the large quantities of UOW generated in them, significantly affects UOW projections and potential management options. Large centralised processing, often at a distance from the site of UOW generation is not fit-for-purpose and closer consideration of on-site management is needed including anaerobic digestion to produce bioenergy. Furthermore, at the council scale, the diversity of contexts, the significant quantities of non-residential UOW not typically considered and the vast array of innovative potential options available at different scales that can help achieve multiple UOW objectives, mean that the historical use of one-size-fits all solutions should be treated with caution.

Over the next 10 years there are major opportunities to transition to more sustainable UOW management practices, especially in Sydney where 20% of the new dwellings in 2036 have not yet been built. The augmented IRP UOW framework developed in this thesis is a way to assist stakeholders at the precinct, council and city scale to improve cross sectoral UOW planning, analysis and decision-making during this window of opportunity.

PART I:

OVERVIEW OF RESEARCH CONTEXT

&

THESIS STRUCTURE

1 INTRODUCTION

In this Section, I present an overview of the food waste and broader yet less explored '*urban organic waste*' (UOW) problem that inspired me to write this thesis. First, I give background on the current global drivers and policy shifts that are providing a window of opportunity to transition the waste industry to more sustainable organics resource management practices. I then situate Australia, and specifically its most populous state, New South Wales (NSW), within the rapidly shifting waste policy context, which is providing both unique opportunities but also potential unintended consequences. This raising the question of whether better insights into food and other broader UOW generation and management are needed together with the development of more nuanced context-specific solutions. Such solutions requiring structured planning, analysis and decision-making beyond those approaches currently used. This leads me to suggest '*integrated resource planning*' (IRP), a practical planning and decision-making approach used for decades in other essential services but to a limited extent in the waste industry, as a potential means to aid transition in the emerging food and broader UOW management sector. I then outline the overall aims, approach and structure of this thesis. The core aims of the thesis are to explore the current generation and management of food and other broader UOW in the Australian context, specifically in the largest city Sydney, and assess the potential for IRP, at both a theoretical and practical level, to assist in advancing UOW management planning, analysis and decision-making practices at this critical juncture.

1.1 OVERVIEW OF THE PROBLEM

1.1.1 A GLOBAL ISSUE

Globally, a third of all food produced for human consumption is lost or wasted, causing not only wasted resources such as labour, water, energy and nutrients but also major sustainability impacts throughout the food system supply chain, from farm production to consumer fork and beyond (FAO, 2011; Hanson & Mitchell, 2017). If 'food waste' was considered a country, it would be the third highest emitter of greenhouse gases (GHG) after China and the US (Hanson & Mitchell, 2017). Due to anticipated population rise, urban growth and densification, as well as increased affluence in developing countries over the coming decades (United Nations [UN], 2015), such waste will increase further per person (Hoornweg et al., 2015) as well as overall. This is unless economic growth is decoupled from resource use and wastage (O'Rourke & Lollo, 2015).

The magnitude of the food waste issue is driving jurisdictions around the world to examine this complex problem and take action. Such actions include adopting the 2015 Sustainable Development Goals (SDGs), specifically Goal 12 (Targets 12.3 and 12.5), which by 2030 aims to:

- "substantially reduce waste generation through prevention, reduction, recycling and reuse", in line with the principles of the ubiquitous waste (management) hierarchy[1], and specifically
- "halve per capita food waste at the retail and consumer level and reduce losses along the production and supply chain, including post-harvest losses" (UN, 2015).

Indeed, many jurisdictions have gone, or intend to go, further than Goal 12. For example, Nova Scotia in Canada has banned landfill disposal of 'compostables' since 1997 (Environmental Research & Education Foundation of Canada [EREFC], 2021), South Korea has banned direct landfilling of 'food waste' since 2005 (Ng, 2013), France has made it illegal for supermarkets to throw food away since 2016 (Condamine, 2020), and California in the US has required residents and business owners to separate 'organic materials' to enable collection for recycling into usable products to avoid disposal to landfill since 2022 (Kamczyc, 2022).

Such examples have grown rapidly in recent years, with many areas aiming to not only restrict food waste from urban landfills but other broader organic waste as well. Other UOW streams including, for example, garden organics, used cooking oils, fats, oils and grease from grease traps, wastewater biosolids and trade waste. The aim of restricting broader organics is to not only help minimise food waste throughout the food system supply chain from production to consumption but also to minimise other impacts, namely leachate and GHGs, associated with the biodegradation of organic materials in landfill. Landfill is currently the predominant waste disposal method used globally (Padmavathy & Anbarashan, 2022). Reducing GHGs is an important objective, especially methane, which is estimated to be 28 times more damaging to the atmosphere than carbon dioxide on a 100 year time scale (IPCC 2014a), due to its contribution to anthropogenic-fuelled climate change (IPCC, 2014b; 2023). Hence reduction in food waste not only helps to achieve SDG 12 but contributes to many other SDG Targets such as: 1 – no poverty; 2 – zero hunger; 3 – good health and well-being; 7 – affordable and clean energy; 9 – industry, innovation and infrastructure; 10 – reduced inequalities; 11 - sustainable cities and communities; 13 – climate action; 14 – life below water; and 15 – life on land.

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[1] While the waste management hierarchy may be a more appropriate term to describe a hierarchy to manage waste and not generate it, it is commonly referred to as the 'waste hierarchy' especially in Australia.

Each country has highly *context-specific* food and other UOW *issues* and thus potential *solutions*. With respect to food waste, overall wastage is higher at the upstream production phase of the food system supply chain in lower income, less developed countries. This is due, for example, to a lack of storage facilities and the deterioration of perishable goods in warm, humid climates. While wastage is higher at the downstream retail and consumer end of the chain in higher income, more developed countries due to issues such as poor menu planning, aesthetic preferences, arbitrary sell-by dates and excess consumerism (FAO, 2011; 2013; n.d.). For example, food waste at the end of the chain in sub-Saharan Africa and South/Southeast Asia is estimated to be only 6–11 kg/person/a. However, in Europe and North America, food waste is closer to 95–115 kg/person/a, with vegetables being an example of high wastage (i.e. 15-30% of purchases by mass discarded) (FAO, 2011; 2013; n.d.).

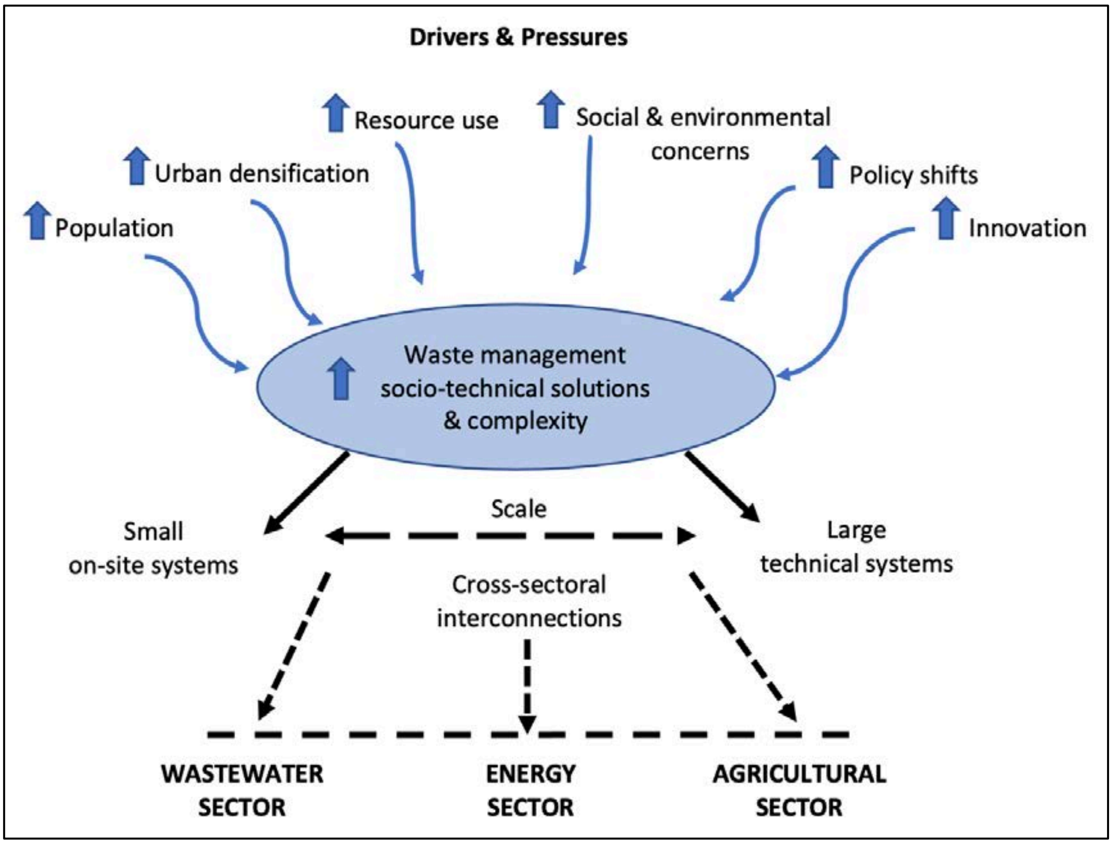
Due to high wastage levels at the retail and consumer end of the food system supply chain in developed countries, many actions are being taken to curb food waste. Such actions include:

- education programs helping to avoid food waste in homes and businesses in the first place such as campaigns on menu planning, food storage and lower priced mishappen fruits and vegetables
- incentive schemes driving smaller, local-scale, '*socio-technical'* innovation in urban settings, encouraging local food and other UOW recovery, on-site treatment and re-use
- policy and regulation, setting aspirational landfill avoidance targets, often driving large-scale technical recycling schemes such as city-wide collection and subsequent industrial-scale composting and/or anaerobic digestion (AD)

Refer to Appendix E for examples of the growing plethora of food and other UOW management solutions being implemented.

Hence, while many countries may have relied heavily on '*large technical systems*' (LTS) (Hughes, 1996; Sovacool et al., 2018) such as city-wide collection and disposal to landfill in the past (refer to Section 2.1 for brief history of waste management practices), there is now an ever-growing number of socio-technical solutions emerging for both food and other UOW. This is driven by a variety of drivers and pressures such as population rise, urban densification, policy change, socio-technical innovation, levels of social acceptance, and public concerns over environmental and social issues. Such solutions result in more complex socio-technical UOW management systems. These systems involve many stakeholders and technologies at various '*scales'* and new direct and indirect '*interconnections*' with other industry sectors such as wastewater, energy and agriculture (see Figure 1.1). These interconnections often produce positive sustainability outcomes and significant opportunities but also examples of '*missed opportunities*' and '*unintended consequences*', such as sewer blockages and corrosion, nutrient loss, and contamination of agricultural soils (refer to Section 1.2.4 - Box 1 for example).

Figure 1.1 – Drivers & pressures resulting in positive & negative cross-sectoral interconnections



1.1.2 AUSTRALIA'S WASTE

Australia, a developed country facing many waste management challenges, particularly those associated with population growth and urban densification in coastal cities, currently has a population of just over 25 million (ABS, 2022). In 2018–19, it produced nearly 0.5 t/person/a of municipal solid waste (MSW), 12.6 Mt/a, a similar per person figure when compared to other Organisation for Economic Co-operation and Development (OECD) countries such as France, Italy and the Netherlands (Pickin et al., 2020). However, the 12.6 Mt/a of MSW produced from households and local government activities represents only 20% of core waste (i.e. waste managed by the Australian waste and resource recovery services sector). Another 21.9 Mt/a of core waste was produced by the commercial and industrial (C&I) sector and 27 Mt/a produced by the construction and demolition (C&D) sector. A total of 61.5 Mt/a, on average 2.5 t/person/a (Pickin et al., 2020).

A large proportion of Australia's core waste is organics: 14.9 Mt/a[2] in 2018–19, representing the second largest core waste stream generated after masonry waste but the single largest stream still passing to landfill (Pickin et al., 2020). This high wastage despite general waste avoidance and resource recovery targets having been in place for well over a decade (Arcadis, 2020a). Based on Pickin et al. (2020) figures, of these organics, approximately 45% is generated by the MSW sector, 50% by the C&I sector and the remaining 5% by the C&D sector, mainly timber (Pickin et al., 2020; Randell, 2020). In 2018–19: half of organics, 6.87 Mt, passed to landfill with 1.28 Mt of this material classified as 'recovered' as part of landfill gas generation; 5.6 Mt was composted or mulched; 1.42 Mt of biosolids was applied to land; and only 0.31 Mt was incorporated into fuels or processed via AD (Pickin et al., 2020). Figure 1.2 provides a breakdown of core waste and a comparison against the large non-core C&I (agricultural and fisheries) organic waste generated.[3]

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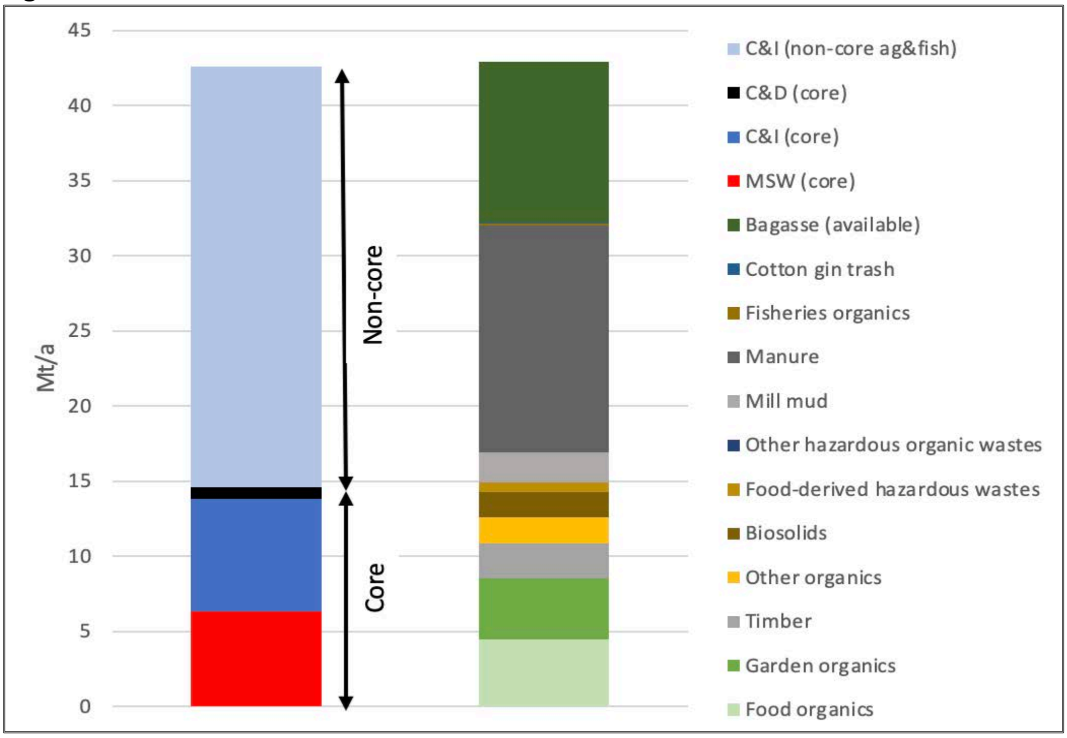
[2] This includes 0.67 Mt of hazardous food-derived materials (i.e. fats, oils and grease from grease traps and abattoir and tanneries waste) and 1.68 Mt of biosolids from sewage treatment (Pickin et al., 2020).

[3] It appears the National Waste Reports do not yet include the food waste generated on-farm and in food processing operations as according to the report '*data on this waste is not yet readily available'* (Pickin et al., 2020). Due to the concerted effort on collecting such data since these reported figures it is assumed that future National Waste Reports would include this additional data. It should be noted therefore that the National Waste Report figures are incomplete and likely to underestimate C&I organics figures to some extent.

Figure 1.2 – National core and non-core waste 2018-19

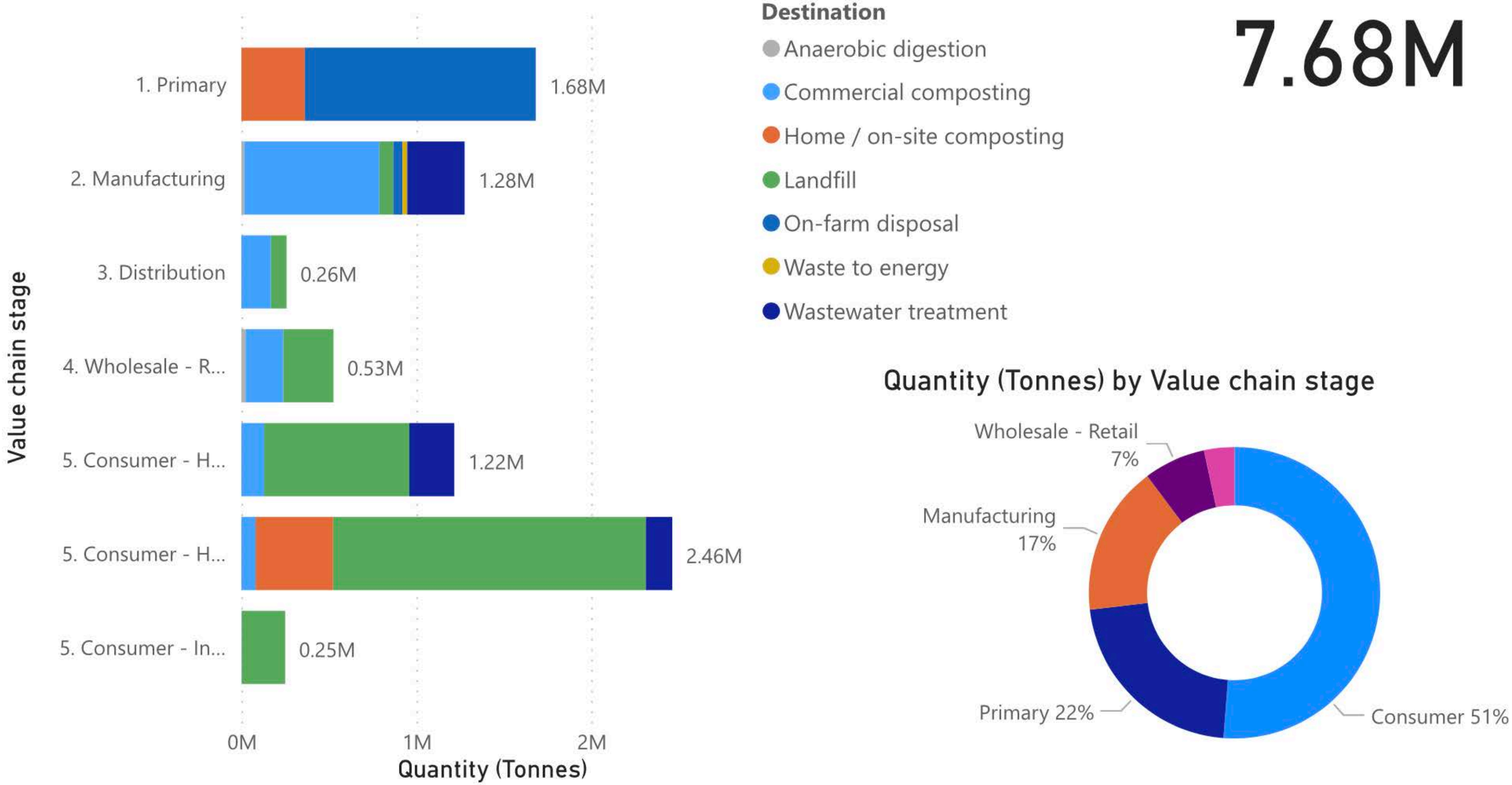


(Source data from Pickin et al., 2020)

According to the most recent National Waste Report at the time of writing (Pickin et al., 2020), in 2018–19, food waste associated with core waste was the largest component, 5.09 Mt/a, with 3.11 Mt in MSW and 1.32 Mt in C&I.[4] Due to the SDGs focus on food waste, subsequent analysis has attempted to establish an Australian food waste baseline along the value chain from production to consumption (Arcadis, 2019; FIAL, 2021). In 2018–19, it was estimated that 7.7 Mt of food waste was generated, with over half at the consumer end of the value chain (including households, hospitality and institutions) with most of this (73%) ending up in landfill (FIAL 2021). Figure 1.3 illustrates the key generation points along the value chain and main destination points. Interestingly, while the 2016–17 (Arcadis, 2019) and 2018–19 (FIAL, 2021) food waste generation figures were similar (7.3 Mt versus 7.7 Mt respectively), the more recent FIAL analysis found that there was less attributable to primary production (i.e. 22% versus 31% reported by Arcadis [2019]) and manufacturing (i.e. 17% versus 24% reported by Arcadis [2019]) but significantly more at the consumer end (i.e. consumer-hospitality was 16% versus only 4% reported by Arcadis [2019]).

[4] 1.99 Mt including the 0.67 Mt of food-derived hazardous waste.

Figure 1.3 - Quantity of food waste by value chain stage and destination



(Source data from FIAL, n.d., reproduced with permission form FIAL)

The reported figures identified for food waste and other broader organics are often difficult to compare due to a number of factors including differences in analysis boundary definitions for various reports, the historical difficulty in gathering such data, and ongoing efforts to improve data collation and analysis methods from such fragmented sources (Arcadis, 2019; FIAL, 2021; Pickin et al., 2020; Randell, 2020). These figures are gradually being improved.

No matter the exact figures, all the analysis identifies the significant quantum of food waste and other broader UOW being generated in Australia and wasted along the value chain. They also highlight, as similarly indicated by international reviews (FAO, 2011; 2013; n.d.), the significant quantities of food waste generated at the retail and consumer end of the UOW value chain and thus the need for developed countries, such as Australia, to contribute to reducing wastage as part of the SDG targets (UN, 2015a).

According to recent analysis, in economic terms, food waste generation alone in 2018–19 was valued at over AUD 36 billion/a as a cost to the Australian economy. The largest proportion, over AUD 19 billion/a, is attributed to households, representing in the order of AUD 2,000 – 2,500 per household/a (FIAL, 2021). Other estimates of associated environmental impacts include:

- 17.5 Mt of CO_2-eq/a generated from the production and disposal of that food waste (excluding emissions associated with exported food), equivalent to 3.5% of Australia's emissions
- 2,628 GL/a of water used to produce that food waste across its life cycle, the equivalent of over 280 L/capita/day if it could be eliminated (FIAL, 2021), and significantly more than the entire volume of distributed water currently used by households in Australia [5].

Due to the high population growth and urban densification on the horizon, especially in the two largest cities, Sydney and Melbourne, food and other UOW generation is only set to increase further along with the associated detrimental impacts if appropriate action is not

[5] Household water use is obtained from a variety of sources depending on the location. These can include non-distributed water collected on a property (i.e. rainwater and bore water). Distributed mains potable water is typically provided by utilities and councils. The average volume of distributed mains potable water used by the more than 9.5 million connected Australian households for the last four years was just over 1,800 GL/a (ABS, 2022) https://www.abs.gov.au/statistics/environment/environmental-management/water-account-australia/latest-release (accessed 29/03/23).

taken to curb generation and disposal and ultimately make better use of these valuable resources.

In response to this mounting issue, national, state and local governments have been addressing food and other broader UOW by going beyond the entrenched historical use of the prescriptive waste hierarchy (CRC Care, 2014; Giurco et al., 2015) and setting specific targets in line with the SDGs (Commonwealth of Australia [CoA], 2017). In addition, they have begun incorporating circular economy principles into policy (CoA, 2018; 2019; NSW EPA, 2018a; 2018b). Such specific targets and principles focus on actively avoiding waste (in line with the intent of the waste hierarchy, SDGs and circular economy) but also the separation of organic waste materials produced to enable better use of resources along the value chain and the reduction of organics passing to landfill. This relatively recent shift to specific food and other broader organic waste targets has resulted in increased effort and investment in food and other UOW avoidance, separation, treatment and use, as discussed in more detail in Section 1.2.

These significant drivers and change in waste policy coupled with population growth, urban densification, socio-technical innovation and social and environmental concern are providing a '*window of opportunity*' to assist in a much needed '*transition*' of the Australian waste management industry. This includes the emergence of a diverse and innovative UOW management sector. However, such significant and rapid change is also posing a risk of missed opportunities and potential long-term negative consequences. An example being the national and state governments as well as key incumbent private waste industry service providers seeing this as an opportunity to introduce service standardisation in the form of large-scale, blanket replacement solutions. These solutions include, in particular, combined food organics garden organics (FOGO) collection and treatment (CoA, 2018; 2019; DPIE, 2021a; 2021b). This blanket approach was proposed despite voiced concerns by many waste industry practitioners about relying on 'one size fits all' or 'silver bullet' solutions (i.e. LTS thinking [Sovacool et al., 2018]) and, in particular, the combining of food waste, which can often be contaminated with, for example, plastics, with the relatively clean garden organics stream (LGNSW, 2019; Wilkinson et al 2021). Such LTS-focused solutions reduce the scope to fully harness emerging innovation at various scales and potentially result in long-term suboptimal sustainability and circular economy outcomes including reduced scope to harness high value chemicals, nutrients and bioenergy.

Specific challenges for achieving optimal outcomes in the Australian context include:

- the fragmented and diverse nature of planning, management and decision-making in waste management (Turner et al., 2019) due to the
    - number of local governments, states and levels of government requiring co-ordination
    - siloed management of the various streams rich in organics
    - reliance on private industry for service delivery, more likely driven by corporate profits rather than sustainability benefits
- the lack of measurement and transparent data sufficient for effective planning in each jurisdiction (Parliament of Australia [PoA], 2018: 2.55-2.57), refer to Section 1.1.2 for details
- the significant diversity in various jurisdictions in terms of urban form, density, socio-cultural habits and environmental issues and awareness (refer to Section 4.0)
- the dominance of risk averse, one size fits all/silver bullet LTS thinking (Sovacool et al., 2018) in developed countries (Guy et al., 2001; Frost et al., 2016; Kosovac et al., 2017) traditionally used by policy makers and planners to solve essential services problems, which increases the risk of LTS *'lock-in'* and innovation and adaptive management '*lock-out'* (refer to Section 3.4.2)
- long waste management contracts established by private waste management service providers to guarantee 'feed stock' to obtain a return on investment, which is at odds with the waste hierarchy, SDGs and the circular economy intent to prioritise efficiency/avoidance (refer to Section 2.2).

Additional complexity in UOW management in the Australian context arises from:

- rapid urban growth and densification (PoA, 2017; SOE, 2021)
- the extent and speed of recent policy change (refer to Table 1.1) but lag in associated regulation (Turner et al., 2019)
- the diverse array of stakeholders involved (Jazbec et al., 2020b)
- the growing number of innovative socio-technical solutions available (Turner, 2020)
- the impact of increasing inter-connection with other industry sectors such as water and energy (Fam et al., 2017; Jazbec et al., 2023).

1.1.3 OPPORTUNITIES TO IMPROVE PLANNING, ANALYSIS & DECISION-MAKING

The waste hierarchy has been used for decades to guide waste management planning both in Australia and globally (refer to Section 2.2 for a brief history). There are, however, numerous additional international and local examples of planning and decision-making frameworks and more detailed models used to help plan, analyse and choose between waste management solutions. Many of the existing examples go well beyond or complement the simple ubiquitous waste hierarchy, by using life cycle analysis/assessment (LCA) or broad options analysis and decision-making frameworks such as cost benefit analysis (CBA), triple bottom line (TBL) and multi-criteria decision analysis/making (MCDA/M); each with their own strengths and weaknesses (refer to Section 2.3 for more details).

However, in practice, such frameworks have predominantly been used to help decide between a limited selection of LTS solutions or where to locate a new facility (Coelho et al., 2017; Asefi et al., 2020). In some cases an LTS organic solution such as composting is considered within a mix of other waste management and recycling options to assess how to extend the life of an existing landfill or achieve a landfill avoidance and/or recycling target as part of an integrated waste management approach (ACT Government, 2018). However, despite food waste and other UOW being such a large component of waste and now very much a focal point of policy makers, there are limited publicly available examples that focus specifically on ways to first quantify the various streams of food waste and then consider a suite of solutions that respond to the specific context being examined.[6] This may be due to the relatively recent emergence of food waste on the policy issue scene (Spang et al., 2019). Nor indeed is there consideration of other broader UOW or associated potential solutions beyond the narrow MSW boundaries of food waste and garden organics typically managed by councils.[7] And there is a significant gap when considering the potential for '*hybrid system*' solutions that move away from one size fits all/silver bullet LTS thinking and intentionally embrace a complementary mix of solutions (Spang et al., 2019), embedded within an existing LTS.

As argued in this thesis, this gap could be filled, and a more agile UOW management system could be facilitated through structured consideration of broader:

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[6] The recent FIAL (2021) food waste feasibility analysis is going a significant way to filling this gap on a national scale but still only providing a partial picture of the potential solutions due to the objectives and boundary scope of the study.

[7] The recent Randell (2020) organics analysis attempted to look at food and garden organics recovery opportunities for MSW and C&I at a national level.

- food and other UOW generated across multiple interconnected systems
- direct and indirect stakeholders involved
- hybrid socio-technical system solutions of various scales available from prevention to recovery
- cross-sectoral opportunities and consequences.

Using such structured planning, analysis and decision-making for the vastly different contexts of Australia could be highly beneficial during this unique window of opportunity.

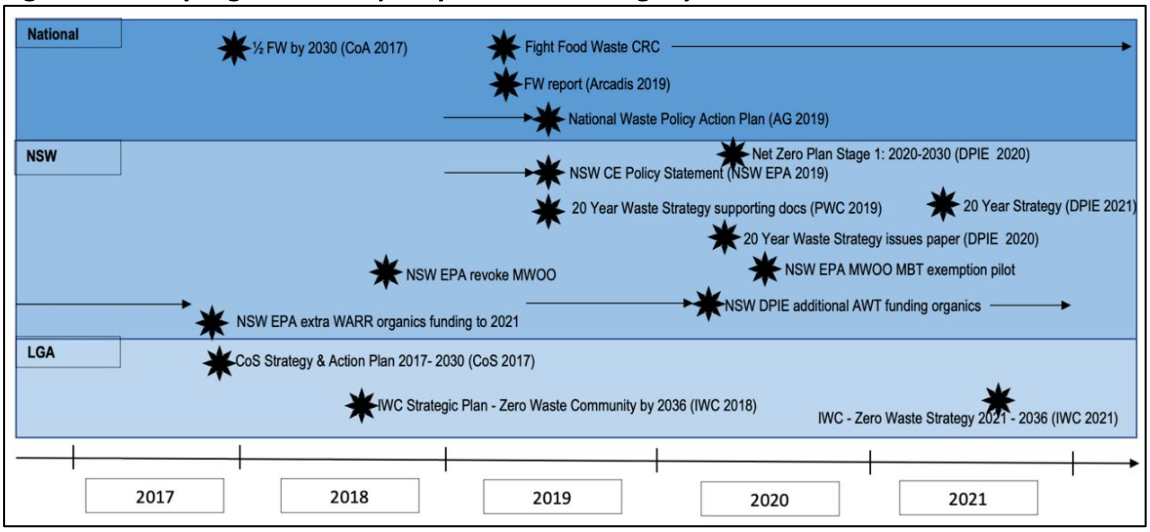
1.2 OVERVIEW OF THE SHIFTING POLICY CONTEXT

To help orientate the reader and illustrate the fast-moving pace of change in the emerging food and other UOW industry sector, in this Sub-Section I provide an overview of the policy context and drivers for change in waste management in Australia, specifically the state of NSW and largest city, Sydney. This helps to explain some of the reasoning behind my choice of research aims, approach and focus, as identified in Section 1.3.

When I first proposed my PhD at the end of 2016 and commenced in mid-2017, there had been somewhat of a hiatus in waste management policy in Australia. However, since then there has been considerable activity around the review of waste management policy and targets at multiple levels of government and the use of economic incentives to stimulate the take-up of new food and other UOW management innovation. There has also been a shift in discourse from focusing primarily on '*food waste*' to, over time, other broader urban '*organics*' waste streams. This was primarily to encapsulate the large garden organics component of waste, which has been managed by the waste sector for years through both pre and post collection separation methods. However, it also helps recognise the other potential organics streams that need to be targeted to help achieve overall waste reduction targets, circular economy aspirations and GHG reductions.

Figure 1.4 provides an overview of some of the key activities that have occurred in parallel to my candidature and helps to illustrate this fast-moving policy context. The most significant changes having occurred at the time of write-up of this thesis, since mid-2021. These changes are now setting the scene for an exciting new era in food and other broader UOW management in Australia, specifically the state of NSW and most populous city, Sydney.

Figure 1.4 – Key organic waste policy activities during my candidature



1.2.1 FEDERAL GOVERNMENT LEVEL

Australian federal, state and territory governments have collaborated on waste policy and actions for many years, with the first comprehensive agreement on domestic waste management agreed to at the national level under the Council of Australian Governments back in 1992 (CoA, 2009). In 2009, a National Waste Policy was agreed to by all Australian environment ministers with an aim to reduce materials passing to landfill and facilitate resource recovery from waste streams to 2020 (CoA, 2009). Based on this policy direction, most states and territories around Australia set landfill diversion targets of between 60% and 90% for MSW, C&I, and C&D waste by 2020 (Ritchie, 2016; Arcadis, 2020a).

At a national meeting of environmental ministers in 2018, it was agreed to update the 2009 National Waste Policy. A Discussion Paper and subsequent Policy Action Plan were released (CoA, 2018; 2019). The documents highlighted the importance not only of food waste but other organics waste streams and the need to "halve the amount of organic waste sent to landfill for disposal by 2030" and aimed for "2.7 million tonnes less organic waste …. to landfill every year" (Target 6) and support action to move to a circular economy (CoA, 2018; 2019). The new plan echoed the government commitment made in 2017 to "halve food waste by 2030" in line with the 2015 SDGs (CoA, 2017). However, the plan went further by expressing the need to focus on other organics more broadly. Although, it also introduced some level of ambiguity. That is, avoiding food waste and other organics "disposed to landfill" not the primary federal government objective which aims to avoid the generation of food waste in the first place.

This ambiguity was amplified by the government's focus on aiming to "reduce total waste generated in Australia by" only "10% per person by 2030 … 300 kilograms less waste every year by 2030" per person (Target 2) and more of a focus on recycling and recovery of waste generated to reduce materials disposed to landfill with an "80% average resource recovery rate from all waste streams … by 2030" (Target 3) (CoA, 2019).

For organics, a key intention identified in the policy documents is to deliver FOGO collection services to households and businesses by 2023, Target 6.4, (CoA, 2018; 2019). A surprisingly prescriptive solution for inclusion in policy and effectively setting a national blanket policy on recycling collection and treatment of the major portion of the core waste generated by both the residential MSW and C&I sectors, that is, the food waste and garden organics waste streams. This setting of a blanket policy without recognition of whether a variety of solutions might be best for:

- different sub-sectors (i.e. residential single unit dwellings [SUDs] versus multi unit dwellings [MUDs], versus different types and sizes of businesses)
- various UOW streams in isolation or combination (i.e. residential food waste, C&I food waste, garden organics, fats, oils and grease from grease traps, used cooking oil or wastewater biosolids)
- different jurisdictions with different characteristics between regional and metro environments and within urban centres themselves.

Nor does such policy seem to recognise that avoidance could, and indeed should, significantly change the quantum of organics collected thereby changing the economics of such services provided or even the fact that many councils have existing long-term contracts with service providers. In fact, many of these contracts expire well after the 2023 target. For example, in Metro Sydney over 85% of council waste contracts expire after 2023 (Arcadis, 2020b).[8] Renegotiating such contracts is likely to incur significant penalties for already financially strained councils. This is an example of the difficulty of including such blanket prescriptive targets and solutions in policy documents.

While the national policy, in terms of the nuance of targets and clarity in messaging, may need some review and tightening going forward to minimise unintended consequences (as do those

[8] During 2022 it was recognised that this target could not be met due to various reasons including COVID-19. Target 6.4 involving the delivery of FOGO services to metropolitan households and businesses is now to be delivered by 2030 (CoA, 2022).

at the state level), the federal government has committed much-needed support to gathering and sharing data. This includes a 10-year research fund, the Fight Food Waste Cooperative Research Centre (n.d.), and the release of new data on the baseline quantities of food waste in Australia (Arcadis, 2019) and subsequent National Food Waste Strategy feasibility analysis (FIAL 2021). The Arcadis (2019) report acknowledging, as found at the international level (Spang et al. 2019), the significant challenges of food waste analysis due to the lack of available reliable data, especially C&I. The recent FIAL (2021) report echoes these difficulties and the need to improve the collection and sharing of detailed data. These data gaps and issues are prevalent across most UOW streams. This not the case in other more mature essential service industries, such as water and energy.

The Australian Government has also continued to release National Waste Reports, which include assessments on food and other organics waste streams, and has committed to release the reports more regularly, every two years (Pickin et al., 2018; 2020). This was a significant gap until recently, with reports previously published in 2010, 2013 and 2017 having a considerable lag between data collection and publication (i.e. the 2010 report summarised data from 2006 to 2007) (Pickin & Randell, 2017). Such lags in publishing data make it difficult to use effectively for research and planning, analysis and decision-making purposes. This general lack of data within the waste management sector was acknowledged as a significant issue prior to the development of the 2009 National Waste Management Strategy by a Parliamentary Inquiry (PoA, 2008: 4.32). It was again raised as an issue more than a decade later during a Senate Inquiry in 2018 (PoA, 2018: 2.55) prior to the release of the most recent National Waste Management Strategy documents (CoA, 2018; 2019). In the most recent inquiry, industry practitioners highlighted that good, accurate and timely data is fundamental to good planning and investment decisions but still lacking in the Australian waste management industry (PoA, 2018: 2.55-2.57), despite some improvements having been made (Pickin et al., 2018; 2020). The recent reporting on national food waste (Arcadis, 2019; FIAL, 2021) is helping to fill this gap at the national level.

Hence, during the most recent National Waste Management Policy review, there was a major shift to target not only food waste, but the largest waste stream passing to landfill: organics. This aimed to help achieve overall waste management targets and align Australia with other jurisdictions in terms of SDG and circular economy aspirations. However, unfortunately, the targets focus more on avoidance from landfill rather than avoidance from generation per se and embed prescriptive LTS replacement solutions within policy, despite industry concern. This is without recognition of the diverse contexts across Australia, the lack of data to fully appreciate that diversity in terms of food and other UOW generation and potential solutions needed, or even whether such prescriptive solutions are actually the most sustainable. That is, the need for context-specific planning, analysis and decision-making of UOW as used in other more mature key essential services such as water and energy.

1.2.2 NSW STATE LEVEL

In NSW, the state government, similar to most states and territories across Australia and internationally, has historically relied on the waste hierarchy as a waste management policy and practice guide. With, according to the objectives of the *Waste Avoidance and Resource Recovery (WARR) Act 2001* (NSW), “resource management options … considered against a hierarchy of the following order: avoidance of unnecessary resource consumption, resource recovery (including reuse, reprocessing, recycling and energy recovery), disposal” (NSW Legislation,2001).

The last 5-year WARR Strategy (2014–2021) defined clear strategies and targets to 2021, including:

- avoiding/reducing the amount of waste generated per person in NSW compared to 2012–13
- increasing recycling rates to 70% for both MSW and C&I waste and 80% for C&D waste
- increasing the volume of waste diverted from landfill to 75%
- specific targets and key result areas around problem waste, litter and illegal dumping (NSW EPA, 2014).

Within the last strategy there were no specific food or other organics waste targets, although there was recognition of the need to both avoid food waste and recycle the significant quantities of food waste and garden organics generated in the MSW and C&I sectors, predominantly discarded to landfill. In the latest publicly available review of the strategy at the time of writing (NSW EPA, 2019), overall, the waste targets were not being achieved (PWC & SIP, 2019a), with food waste and garden organics still seen as major streams to focus on to achieve diversion rates (PWC & SIP, 2019b). While the waste hierarchy and non-specific waste stream targets have assisted NSW to reduce waste generation and increase recycling and recovery to some extent, especially the C&D sector (PWC & SIP, 2019a, p.42), this has had less of an effect on the large organics component. This is demonstrated by the fact that organics is still the largest waste stream passing to landfill (Pickin et al., 2020) with continued associated significant potential economic, social and environmental impacts.

1.2.3 NEW NSW 20-YEAR WASTE MANAGEMENT STRATEGY

In 2018, in line with the federal government, the NSW Government released a discussion paper and policy statement on the circular economy, which included the need to '*value organics*' (NSW EPA, 2018a; 2018b). From 2019 to 2021, the NSW Government developed the latest waste strategy, with an issues paper and supporting documents released in early 2020 to assist in industry engagement (NSW Department of Planning Industry and Environment [NSW DPIE], 2020a; PWC & SIP, 2019 a, b, c; ARUP, 2019). As a result, two key reports relevant to UOW were released in mid-2021 at the time of writing:

- *NSW Waste and Sustainable Materials Strategy 2041: Stage 1 2021-2027*
- *NSW Waste and Sustainable Materials Strategy: A guide to future infrastructure needs* (NSW DPIE, 2021a; 2021b).

This 20-year waste strategy builds on the NSW Government's significant efforts on waste management and previously issued 5-year Draft Infrastructure Strategy (NSW EPA, 2017), released for consultation but never finalised. This was likely, in part, due to industry criticism indicating the need for a longer-term strategic direction and certainty (Local Government NSW, 2017).

The new strategy's key targets/focus areas now have far greater emphasis on organics, and in the most part, mirror the federal government aspirations. Those relating to UOW from NSW DPIE (2021a) include:

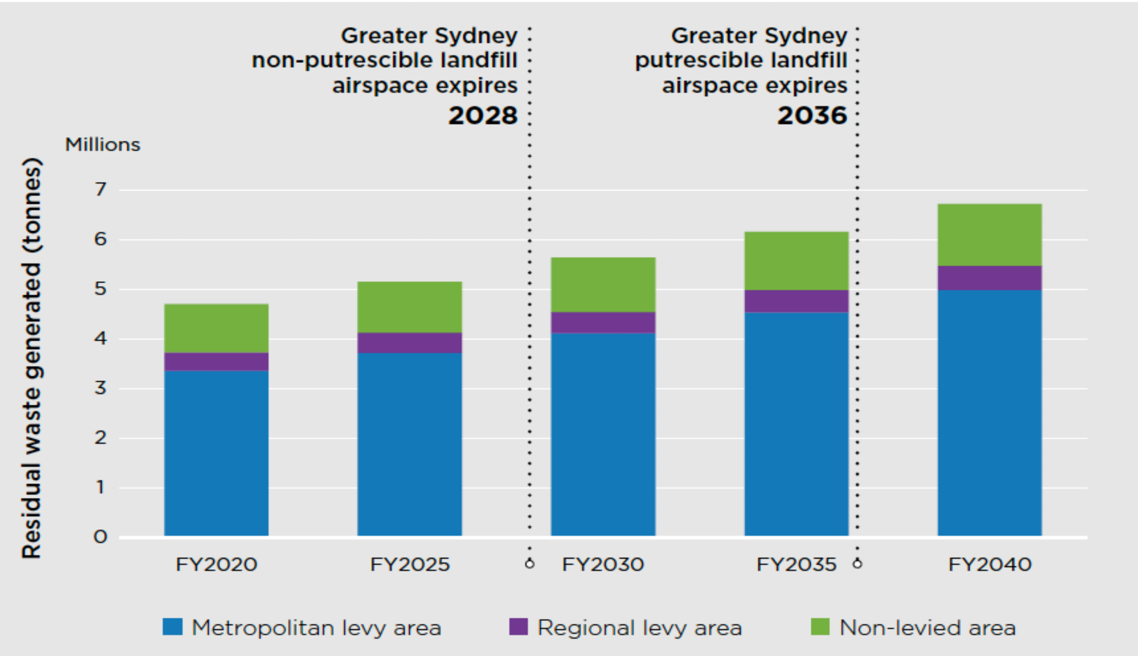
- reducing total waste generated by 10% per person by 2030
- having an 80% average recovery rate from all waste streams by 2030
- halving the amount of organic waste sent to landfill by 2030
- mandating the separate collection of
    - FOGO from all NSW households by 2030
    - food waste from targeted businesses and other entities that generate the highest volumes of food waste, including large supermarkets and hospitality businesses by 2025

- reaffirming the commitment to the goal of net zero emissions from organic waste by 2030, as set out in the Net Zero Plan Stage 1: 2020 – 2030 released in early 2020 (NSW DPIE, 2020b).

Similar to that identified at the federal level, the emphasis of the new NSW strategy is avoidance/diversion from landfill and associated recovery, rather than avoidance per se, with only a minor reduction in per person waste generation of 10% expected. This, again, appears at odds with the intent of the National Food Waste Strategy that is expecting to halve food waste. With recent associated modelling and recommendations focusing on avoidance in primary production but also relying on significant reductions from avoidance in the residential MSW (30% reduction) and C&I (over 50% reduction) sectors (FIAL, 2021).

The new NSW strategy also identifies significant infrastructure needs with state waste volumes predicted to almost double from 21 Mt/a to 37 Mt/a over the next 20 years and Sydney's limited non-putrescible and putrescible landfill sites predicted to reach capacity within 10 and 15 years respectively under a business as usual (BAU) scenario. With the BAU already including a significant quantum of recycling (NSW DPIE, 2021a), see Figure 1.5, although the assumptions behind BAU and projections are not detailed within the reports.

Figure 1.5 – Projected BAU residual waste (residential & non-residential) by levy area



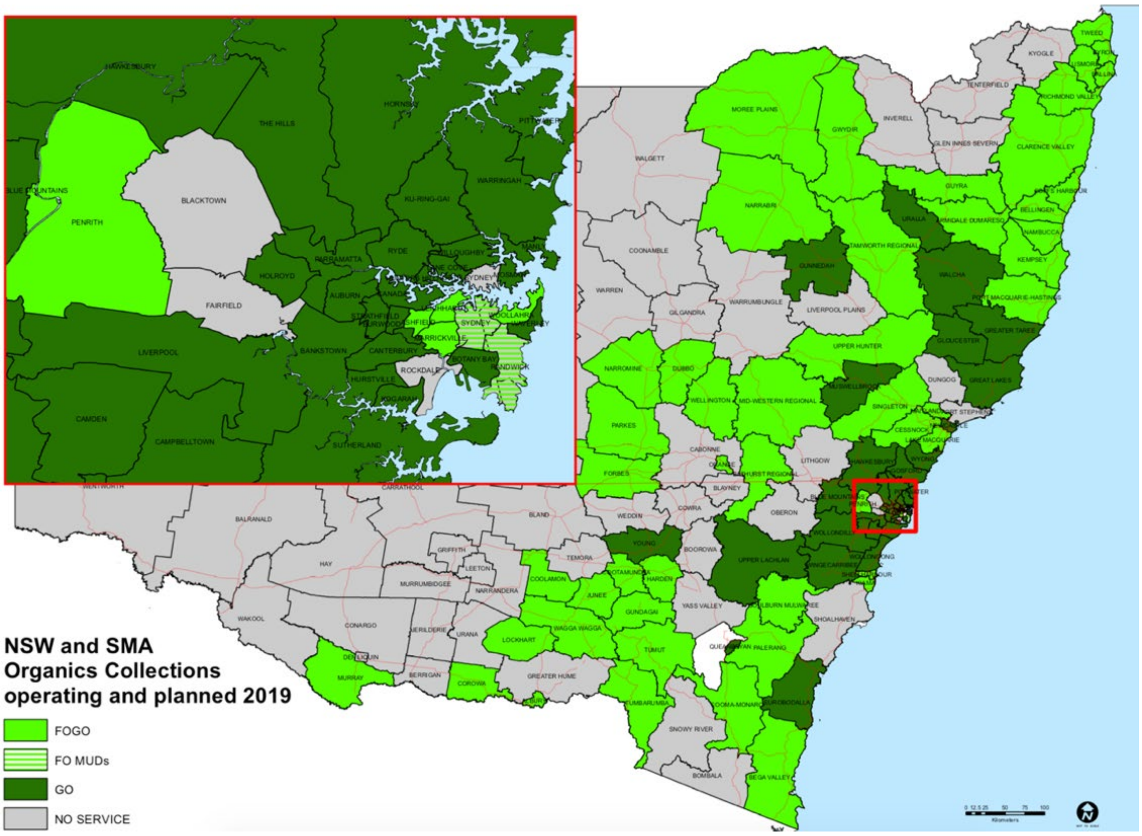
(Source: NSW DPIE, 2021a)

The new NSW strategy identifies that the gap for UOW not only needs to be filled with LTS composting, the dominant solution in discourse for over a decade, but also with new large- and medium-scale AD as well as other smaller on-site solutions (NSW DPIE, 2021a; 2021b). The mandating of organics separation at source and acknowledgment of the opportunities of AD is a major shift in government policy direction over the last five years and was supported by a broad spectrum of waste management industry practitioners when consulted prior to the release of the latest policy documents (Turner et al., 2017; 2019). The inclusion of AD now opens the door to improved policy alignment with other industry sectors (i.e. linkage between waste and bioenergy). Although, the continued dominant discourse specifying FOGO collection, which is laced within many recent policy documents (CoA, 2019; NSW DPIE, 2021a; 2021b), is potentially jeopardising AD opportunities, as discussed in Section 1.2.4 below.

1.2.4 FUNDING

NSW has the highest landfill levy in Australia, having risen from AUD 20 to 146 per ton between 2006 and 2021 in the Sydney Metropolitan Levy Area (Ritchie, 2016; NSW EPA, n.d.-a), see Section 4.2 for boundaries. These levies have provided significant funds and incentives for waste management initiatives. The Waste Less Recycle More program, worth AUD 802 million over the last 9 years (NSW EPA, n.d.-b) which came to an end in 2022, included a specific AUD 105.5 million Organics Infrastructure Fund to boost food waste and garden organics recycling and reduce organics sent to landfill. While much of the funding was used for avoidance programs and innovative on-site technologies, a significant proportion was used by regional councils for collection and treatment. Over 40 regional councils now have FOGO services and associated LTS composting, compared with only a handful in Sydney, as shown in Figure 1.6.

Figure 1.6 – NSW organic waste collection (operating and planned) in 2019



(Source: Wall, 2020)

The lag to take up FOGO collection and treatment in Sydney is due to many socio-technical reasons, such as historical FOGO capacity issues, concerns over contamination of well-established garden organics services,[9] public confusion on what and how to recycle, and reliance by many councils on long-term contracts with existing alternative waste treatment/mechanical biological treatment (AWT/MBT) services (LGNSW, 2019). Such treatment services used to remove materials including organics from MSW after collection and prior to landfill was first set up and funded by the NSW Government in the late 1990s to help councils achieve MSW landfill diversion rates (Wall, 2020). These systems are now predominantly owned and managed by private service providers, such as the large modern MBT facilities at Woodlawn, 200 km south of Sydney. The long-established reliance on such collection and treatment systems in Sydney is now in jeopardy due to policy reversal on the outputs produced (see Box 1).

[9] Contamination issues are also a concern at a national level (Wilkinson et al 2021).

Box 1 – Mixed waste organic outputs

Figure – Example of physical contamination

Shock waves were sent through the Australian waste industry after the China National Sword Policy, January 2018 (Downes & Dominish, 2018). Similarly, in October 2018, the NSW EPA revoked the mixed waste organic outputs orders and exemptions, after the material had been used for nearly 20 years for soil amendment for mining rehabilitation and on agricultural and forestry land. The policy was revoked due to the NSW EPA questioning the efficacy of the mixed waste organic outputs produced. The EPA cited potential risks associated with chemical and physical contaminants (see Figure), with research indicating that at low application rates there is little benefit in terms of crop production/beneficial effects, but at higher application rates there are contamination risks (WMR, 2019; Wall, 2020; NSW EPA, 2020).

This policy shift away from mixed waste organic outputs led to major ramifications for existing waste management contracts. For example, the South Sydney Regional Organisation of Councils (SSROC), responsible for waste management of a third of Sydney residents in the metro area, had to deal with an MBT contract (that took a decade to refine and had 9 years left to run) not fit for purpose (SSROC, 2020). It also resulted in the NSW Government having to release five-year exemption pilots and additional funds to aid such councils (and the MBT owners who ceased production in 2018) to continue operations for an extended period but only allow the materials to be used for limited purposes (i.e. dam tailings fill). This occurring while other investigations and arrangements were made to shift to source separated organics and treatment (i.e. FOGO), while minimising the effect on landfill diversion and recycling figures.

Another emerging concern with FOGO is with respect to AD, which has only recently been considered as a potential solution for food waste and other UOW in Australia despite its use for decades in other jurisdictions such as Europe. The combined on-site collection of FOGO for households and businesses is forcing the potential need for additional and likely expensive pre-treatment methods before AD treatment as well as post digestion treatment (Steffen et al., 1998). This is due to the complication of mixing lignin-rich garden organics with food waste, which has far greater AD compatibility and bioenergy potential when kept separate from garden organics and treated as a single stream or co-digested with other organic materials such as fats, oils and grease and/or wastewater biosolids (Jazbec & Turner, 2018; Jazbec et al., 2022; Jazbec et al., 2023).

Hence, a significant proportion of the funding of AUD 356 million committed for the new 20-year waste management strategy (NSW DPIE, 2021a) will need to be channelled towards UOW management solutions in Sydney. This needed to deal with the move away from mixed waste organic outputs produced by AWT/MBT and the implementation of new mandatory organics source separation, FOGO collection and treatment as well as other on-site treatment and new AD facilities to help achieve organics targets. Such funding, however, is likely only a fraction of what is required due to the NSW Government's continued reliance on private sector investment for essential services infrastructure. The reliance on private funding arrangements further complicating UOW management planning and decision-making processes.

1.2.5 RESEARCH RELEVANCE

This Sub-Section has highlighted the significant shift in food and other UOW policy and discourse, especially in NSW and Sydney, over the last five or so years (i.e. during my candidature). Table 1.1 summarises these shifts.

Table 1.1 – Key shifts in food and other organic waste focus since 2017

2017 focus	Current focus
• the waste hierarchy	• the circular economy
• halving food waste by 2030	• halving organics sent to landfill by 2030
• no mention of food waste or organics separation in policy	• planned mandatory ○ FOGO separation at source in households by 2030 ○ food waste separation from many larger businesses by 2025
• concern over the paucity of waste data	• acknowledgement of the significant gaps in food and other UOW data, especially in the C&I sector • need for greater data collection & sharing
• establishment of modern MBT facilities and associated contracts to produce mixed waste organic outputs post collection	• by 2018–19 a reversal in policy and the use of mixed waste organic outputs restricted to limited applications due to contamination concerns
• no mention of AD in waste management policy	• specific identification of large- and medium-scale AD needed in Sydney by 2030 and 2040

Given the shifts shown in Table 1.1, some of the key identified foci of my research that were initially conceptualised in 2016–17 are now part of the current discourse and policy vision of how the new food and broader UOW management industry needs to manage organic resources going forward. These including the need to consider:

- food waste together with other broader UOW streams to help garner a more complete picture of the organics being generated in urban environments and its potential

- restricting UOW passing to landfill through specific organics targets similar to other countries and individual jurisdictions
- filling food and other UOW data gaps, especially C&I, to help clarify the problem and identify potential management solutions
- going beyond the traditional use of the ubiquitous waste hierarchy, which has been used for decades but does not address the complexity of UOW or enable comparison of different options or scales needed
- incorporating AD, which is significantly underutilised in the Australian context, in organics management.

Still missing from the waste management discourse, however, and more important than ever, is the need to consider *how* to incorporate such foci in a structured way, and in doing so:

- garner a broad yet more detailed understanding of the emerging, complex socio-technical UOW management system to assist in ascertaining how it can be planned and managed more effectively
- avoid LTS lock-in and innovation and adaptive management lock-out in shifting policy and urban environments where socio-technical innovation is rapidly emerging
- make informed and context-specific decisions on the solutions to use at various scales, including embedding hybrid solutions, to maximise positive cross-sectoral sustainability outcomes and minimise unintended consequences.

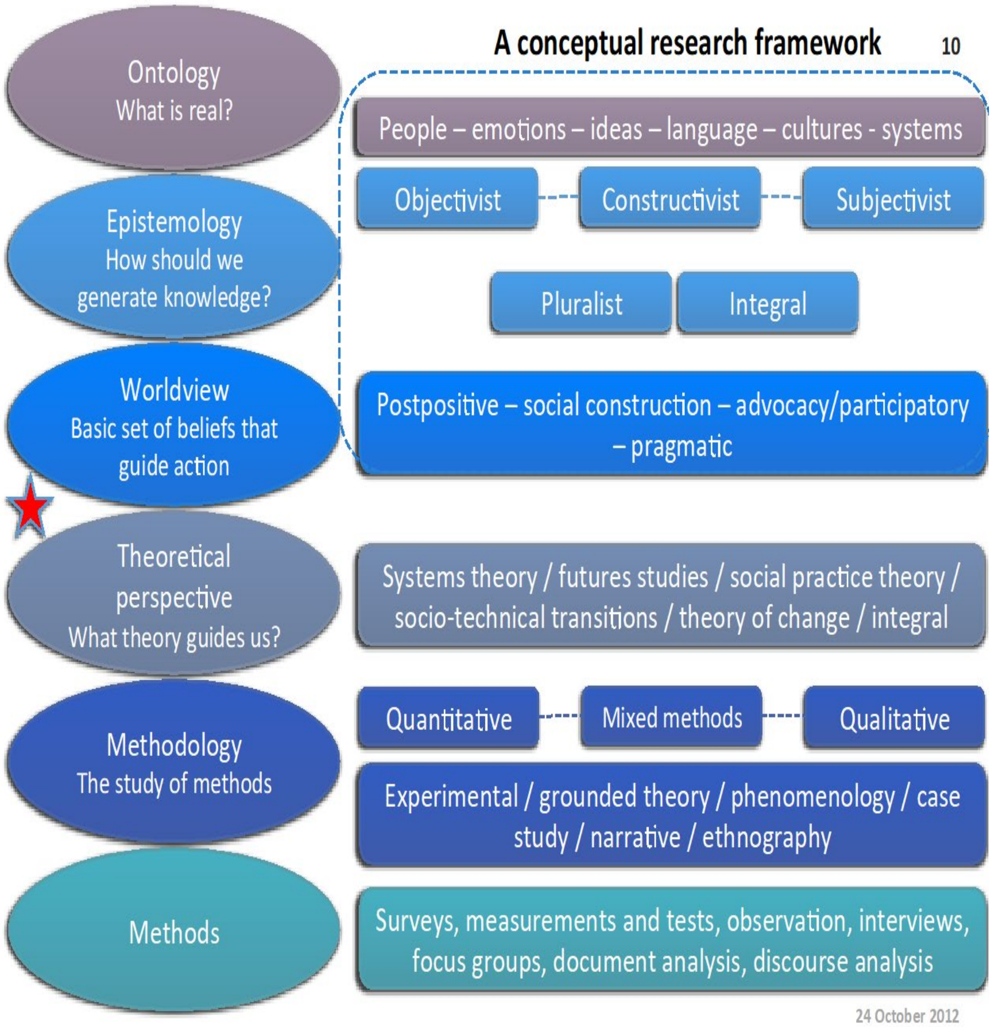
Hence, despite the shifts to date (or perhaps because of them) the focus of my research (including specific Sydney investigations) can assist in filling many current gaps in industry knowledge and help the industry transition over the next five to ten years in Sydney, and other similar dense urban environments.

1.3 OVERVIEW OF THE RESEARCH APPROACH

1.3.1 LENSES

There are many ways to view the UOW problem, but from an academic perspective, the theoretical lenses, methodologies and methods need to align. Using the conceptual research framework shown in Figure 1.7, adapted from frameworks developed by Crotty (1998), Goodrick (2007) and Creswell and Creswell (2009), in this Sub-Section I outline the approach to my research.

Figure 1.7 - Research Framework



(Source: ISF, 2012)

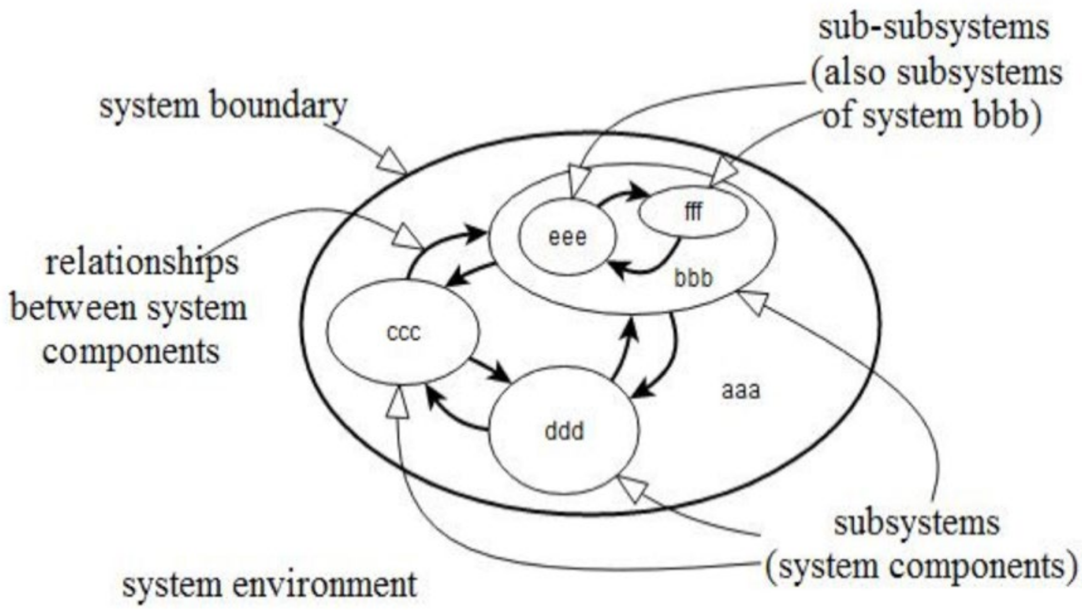
Drawing on Crotty (1998), Goodrick (2007) and Creswell and Creswell (2008), due to my formal academic training in engineering and science (i.e. Bachelor of Engineering in Civil Engineering and Master of Science in Environmental Engineering), I acknowledge that my ontological and epistemological perspectives predominantly lean towards the objectivist end of the spectrum. However, due to many other personal and professional experiences in my life, including over a decade of international engineering contracting and consultancy followed by more than two decades of applied research in sustainability, I have shifted somewhat towards a constructivist perspective. Hence, depending on the research in question, I am comfortable taking a pluralist perspective. This recognises the value of both objective and subjective approaches and the different kinds of theoretical perspectives, methodologies and methods that stem from them, which in combination, can often provide a richer and more holistic view of the subject being investigated.

Based on Creswell's philosophical worldviews (2008), and because I am fundamentally drawn to real-world problems such as UOW and trying to find appropriate solutions if they are feasible, in this thesis I take a pragmatic position to research in which I:

- focus on the research problem and use all approaches available to help understand that problem
- value the use of pluralistic approaches to generate knowledge
- am orientated towards real-world practice
- am outcomes-focused, looking at 'what' and 'how' to research to achieve the desired outcomes.

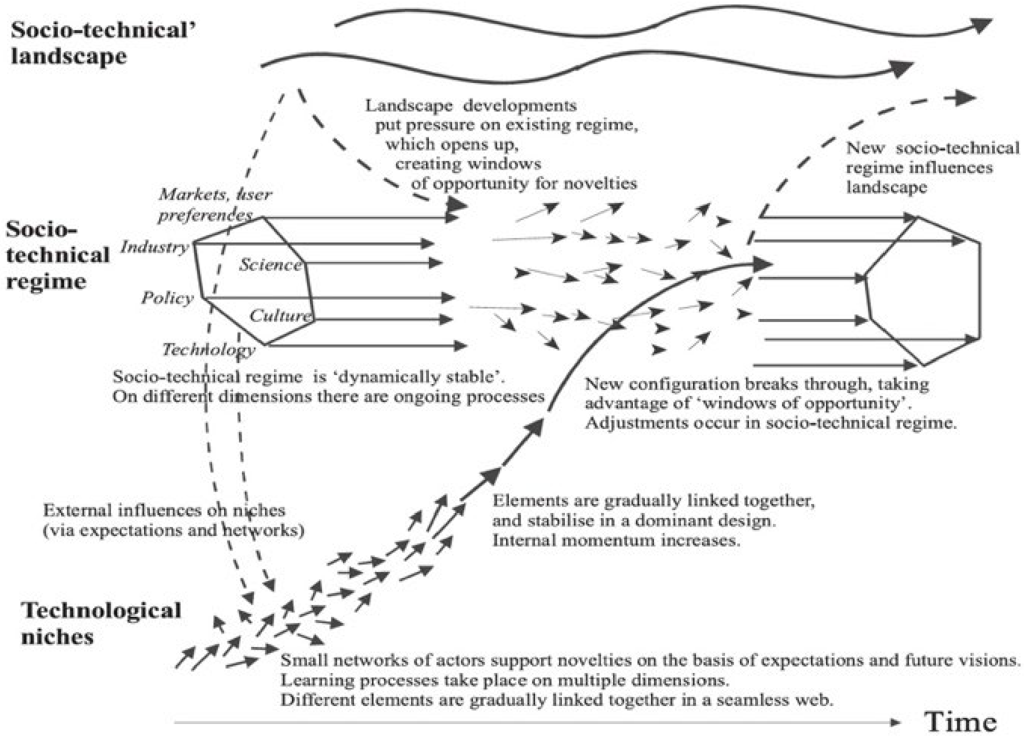
Unpacking food and other UOW and finding context-specific solutions is a highly complex real-world problem that can significantly benefit from practical outcomes-focused research. Hence from a theoretical perspective, I have chosen to view the problem, see Figure 1.8, using the practical IRP framework supported by two complementary theoretical lenses of (i) systems thinking and (ii) sustainability transitions.

Figure 1.8 – Illustration of lenses used in this research
(a) Illustration of systems



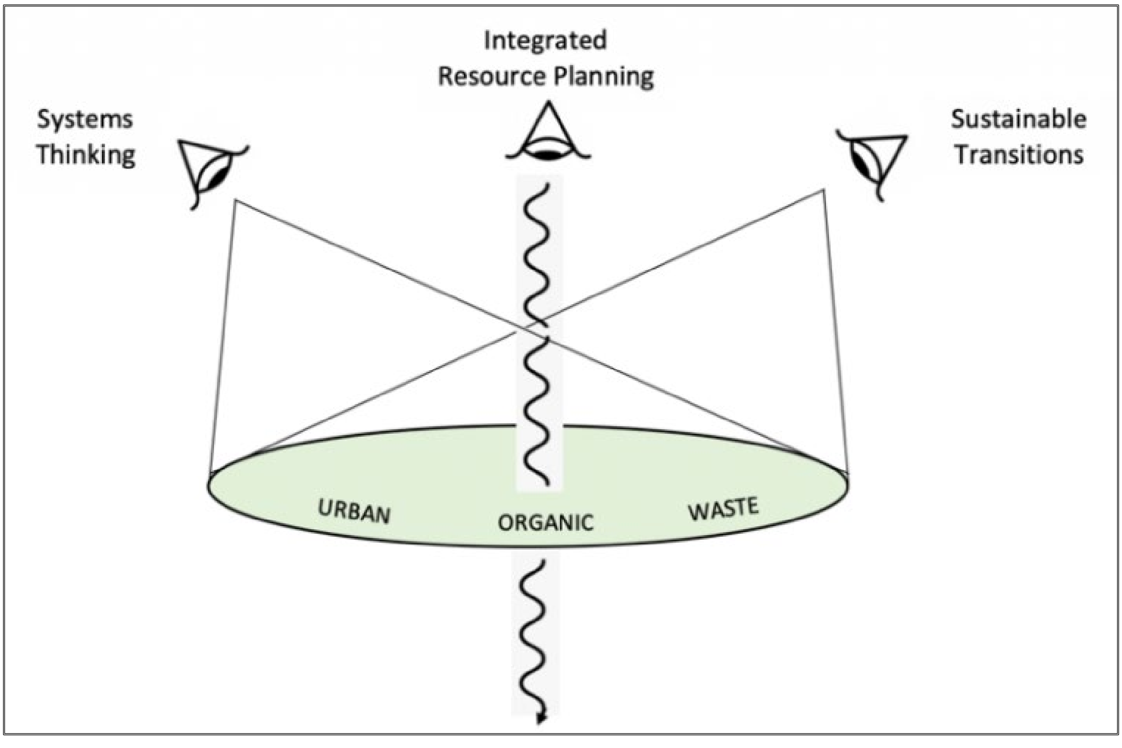
(Source: Armson, 2011. Republished with permission of Triarchy Press Ltd via PLS)

(b) Multi-level perspective of socio-technical systems from sustainability transitions



(Source: Geels, 2002 in Sorrell, 2018)

(c) Proposed use of IRP lens supported by systems thinking & sustainability transitions



Firstly, I specifically chose the IRP framework due to its ability to help obtain a more holistic picture of the resource/s in question (i.e. multiple UOW streams) in a specific context with whatever data is available. Secondly, for its ability to help develop the hybrid system responses needed for that specific context (i.e. a mix of scales of solutions in multiple residential and non-residential sectors and sub-sectors). This approach has been used for decades in mature essential services industry sectors such as water and energy in multiple and diverse jurisdictions as such systems have transitioned away from relying predominantly on one size fits all/silver bullet LTS, which have become less effective. For example, in the case of water moving away from rain-dependent dams that have sustained cities for decades but are now dramatically affected by climate change, to a more diverse portfolio of solutions. These solutions include a mix of water efficient home devices, on-site rainwater tanks and regional recycling schemes as well as large-scale desalination plants (Turner et al., 2010a; 2016). Surprisingly, while IRP may have been successfully used for decades in water and energy planning and decision-making, it has had limited, if any, application in the waste management sector or specifically in the emerging UOW management sector (CRC Care, 2014; Giurco et al., 2015; Turner & Fane, 2023). Potential reasons for this are discussed in Section 3.2.2.

Looking at such a well-established planning, analysis and decision-making framework poses a major opportunity for the emerging food and other UOW management industry sector. This is because it helps open the door to efficiency/avoidance, which despite the waste hierarchy's focus, is still under-represented in waste management literature and practice for food waste (Mourad, 2016; Redlingshöfer et al., 2020; Spang et al., 2019). Also, because it advocates lower cost, more sustainable and flexible hybrid socio-technical systems that specifically embrace various scales of solutions tailored to specific contexts (Turner et al., 2010a). Such flexible hybrid systems are sorely needed during this unique window of opportunity and period of uncertainty and rapid change associated with urban growth and densification, policy shifts and alignments, growing stakeholder involvement, public awareness as well as burgeoning socio-technical innovation.

I have specifically used systems thinking as an additional lens primarily because, while not explicit, it forms the foundational theory supporting IRP (Turner & Fane, 2023). Systems thinking helps to focus attention on the service being delivered and to disaggregate and view the multiple streams of UOW, the inter-connecting socio-technical systems, subsystems and components, while also maintaining a holistic view and being cognisant of the potential positive and negative interactions with other systems (Turner & Fane, 2023).

I have also used sustainability transitions as an additional lens, primarily because it similarly has foundations based on systems thinking (Geels, 2004), but importantly, it has additional useful perspectives. These additional perspectives include a futures focus and the use of the multi-level perspective, which helps to tease out the landscape drivers, current regime and innovative niche socio-technical systems emerging during a window of opportunity for transformative change (Geels, 2002; Geels & Schot 2007; Sorrell, 2018).

Each lens has benefits and limitations, but together they provide a useful, more holistic picture of the UOW system from multiple but aligned perspectives. These theoretical lenses, their key principles and alignment, are discussed further in Section 3.0.

1.3.2 RESEARCH AIMS & QUESTIONS

Hence, in this thesis I aim to focus not just on the food waste problem but the less explored and broader UOW management problem, which encapsulates additional streams of organic waste, such as garden organics, used cooking oil, fats, oils and grease and wastewater biosolids all found in dense urban environments.

I examine Australia and specifically the largest city, Sydney as a case study along with a series of opportunistic nested case studies within Sydney, ranging in scale from mixed use building/precinct to council LGA, to help examine the problem in more depth. Sydney was specifically chosen for the research because it is a:

- representative of a city in a developed country, going through rapid growth and urban densification, which is causing waste management issues
- jurisdiction impacted by rapid UOW management policy change and growing complexity
- city with an acknowledged need to improve UOW management
- location with multiple progressive industry stakeholders wanting to fill specific UOW management knowledge gaps that can be used in Sydney, and also potentially other areas of NSW and Australia.

At a theoretical level, I aim to discuss, supported by over 20-years of personal research experience in the water industry, how IRP, a well-established practical planning and decision-making approach used in other essential service industries for decades, could help fill the gaps identified in waste management planning, analysis and decision-making. Further, I specifically aim to explore how, through augmentation with systems thinking and sustainability transitions theoretical lenses, IRP could help improve planning, analysis and decision-making in the emerging UOW management sector while also acknowledging potential limitations.

At a detailed level I aim to use the Sydney-based case studies to help address specific UOW management industry gaps identified by the literature and industry leaders and practitioners. Such gaps include the types and quantities of UOW at various scales in Sydney and the range of potential options available at different scales to help manage those materials in specific contexts, especially smaller, local-scale, innovative socio-technical solutions entering the market.

Finally, at a practical level, based on the case study investigations and use of various IRP, systems thinking and sustainability transitions methods used within those case studies (i.e. ranging from stakeholder and data identification and analysis through to options development and visualisation), I aim to identify ways of improving the IRP approach. These improvements can be used specifically for UOW management planning, analysis and decision-making in the future, but also, in some cases, water IRP application as well.

Hence my three overarching research questions include:

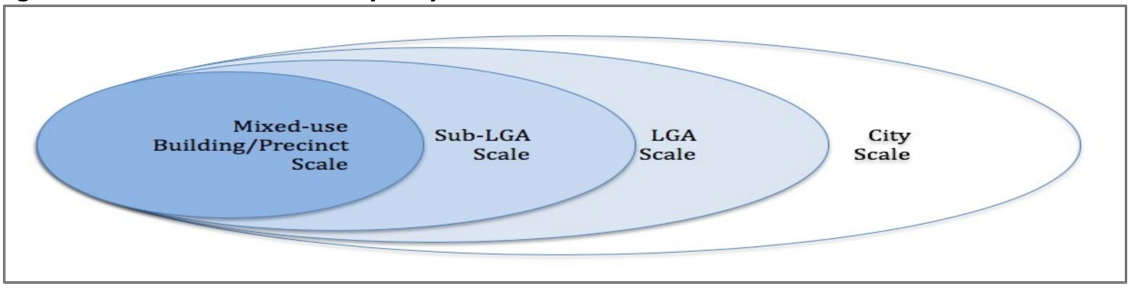
- What are the gaps and opportunities in UOW management planning?
- How can this be strengthened in theory and practice through systems thinking, sustainability transition management and IRP?
- What insights can be drawn from the water sector given the similarities and differences between water and waste and the associated sectors?

1.3.3 METHODOLOGY & METHODS

In line with my pragmatic worldview, my methodology is based on a mixed methods approach using a combination of quantitative and qualitative data drawn from multiple sources. At the core of the methodology I use a series of Sydney-based nested case studies that have opportunistically emerged during my candidature. Each case study was developed using a transdisciplinary team-based approach involving, to a greater or lesser degree, the co-design, co-production and co-dissemination between me working in the academic applied research field and various industry practitioners/stakeholders from various disciplines (Mauser et al.

2013) working in a variety of industry sectors. The case studies focus on identified gaps at different geographical scales, as illustrated in Figure 1.9, and were developed with industry leaders prepared to fund applied research projects. The research was designed to not only fill the specific UOW knowledge gaps at those scales, but also to inform UOW management more broadly for Sydney, the state of NSW and the UOW management sector within Australia, to assist in its transition to more sustainable practices.

Figure 1.9 – Various scales of Sydney-based nested case studies



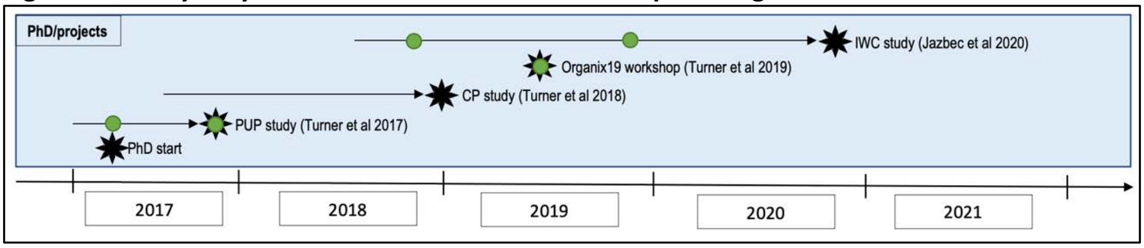
My pragmatic worldview, systems-based lenses, mixed methods approach using case studies developed with key stakeholders together with an outcomes focus, are all consistent with transdisciplinary research. The use of systems-based approaches (as used here with all three lenses, especially soft systems approaches discussed further in Section 3.3.1), as a way to draw together both concepts and methods applied, is inherently transdisciplinary (Ison, 2017). So too is the outcomes-driven focus, purposefully drawing together and integrating a variety of methods from different disciplines, with the key aim of improving the situation being investigated (Mitchell et al., 2015). This was the case for each of the individual case studies and the broader UOW management sector as a whole in terms of generating new knowledge to assist the emerging UOW management sector transition to more sustainable practices through improved planning, analysis and decision-making.

As is common in transdisciplinary applied research (and PhDs for that matter) case studies are subject to change in scope and timing due to the nature of this type of research. They are also subject to change due to unforeseen circumstances arising during the research process. This was the situation with the case studies investigated. Hence, the case studies here do not provide perfect experiments but a partial jigsaw that provides glimpses to glean a better picture of the UOW problem and potential solutions in the Sydney context to draw informed conclusions that can be used more broadly. Nor do the case studies specifically use a full IRP framework due to various constraints, but they do use many of its key concepts and methods as part of the investigations, along with applications of methods from systems thinking and sustainability transitions.

The case studies, timing and stakeholders involved are briefly summarised in Table 1.2, which illustrates the diversity of stakeholders and practitioners involved in the research. Full details of the case studies, stakeholders, my involvement, the specific mixed methods used, and findings are summarised in Section 5.0. All the case studies provide a unique perspective on UOW not previously used in the Sydney context and seemingly missing/limited in the broader Australian and even global context, hence adding to the body of knowledge in multiple ways.

As part of the mixed methods used, a series of workshops, both a large industry workshop with a broad selection of practitioners and smaller-scale workshops with selected industry partners, were used to collect data as part of the case studies during the PhD research period, as shown in Figure 1.10. Organix19 was a stand-alone, two-day workshop involving over 65 participants. It provided a broad industry snapshot of the Sydney UOW context, vision and potential paths to transform to a circular economy using a sustainability transitions theoretical perspective and was useful in providing context for all three of the Sydney-based case studies. The workshop was conducted before the new NSW 20-year waste management strategy was released in mid-2021 (NSW DPIE, 2021a) and helped to inform the NSW Government on the food and broader UOW aspect of the waste management strategy.

Figure 1.10 – Sydney-based case studies and workshops during candidature



In Figure 1.10 the stars show project completion and green dots core interviews and small- and large-scale workshops during each project.

Table 1.2 – Summary of case studies

CASE STUDY TITLE/SCALE	YEAR	STAKEHOLDERS	Core aim of research
Central Park (CP) Precinct Organics Management Feasibility Study > mixed use building/precinct scale (Turner et al., 2018)	2017-2018	Funding City of Sydney (council) – innovation fund Flow Systems (private utility) Involved in research Flow Systems JLL (property managers) Active Research (AD specialist) Avac (vacuum specialist)	assess, at a high level, the feasibility of innovative technology, specifically on-site AD and vacuum systems, at the mixed use building/precinct scale investigate the various types, volumes/tons and bioenergy potential of on-site UOW at One Central Park (mixed use building) specifically investigate One Central Park, within a AUD 2 billion 5-star Green Star development in Sydney, as potential for grant/industry pilot and demonstration site for future precinct developments
The Pyrmont-Ultimo Precinct (PUP) Scale Organics Management Scoping Study > sub-LGA scale (Turner et al., 2017)	2017	Funding Sydney Water (public water utility) NSW EPA (government department) Involved Smart Locale (group of local sustainability professionals) Interviewed Representatives from private & public utilities, state & local government & technology providers Workshop As above plus university, regions of councils, retail & other NSW Government representatives	investigate and map, at a high level, the volumes/tons of various types of UOW in the PUP area in the heart of Sydney, at the time the highest population density in Australia investigate innovative UOW management solutions & suite of illustrative options that could potentially manage UOW in the area garner insights that might be useful for Sydney more broadly and lead to a pilot in the PUP area
Organics Revolution: Planning for 2036 and Beyond (IWC) > LGA scale (Jazbec et al., 2020a; 2020b)	2018-2020	Funding Inner West Council Involved Council, Sydney Water & NSW EPA (data) Workshops Council staff	build on the learnings from the previous two studies map UOW generation at the LGA scale update and expand the inventory of options available develop a suite of illustrative options for IWC go further into the assessment of costs & benefits of options explore decision-making approaches

The mixed methods approach was used to help elucidate the:

- UOW problem
- types and quantities of UOW in Sydney and gaps in knowledge
- potential socio-technical solutions available
- existing planning and decision-making approaches used in waste management together with identification of potential gaps and opportunities
- theory behind IRP and how augmenting it with systems thinking and sustainability transitions lenses could potentially improve it both theoretically and practically for potential future use in UOW planning, analysis and decision-making.

The suite of methods used in the various 'Parts' of this thesis are shown in Table 1.3, along with the associated Section chapters.

Table 1.3 – General research methods used

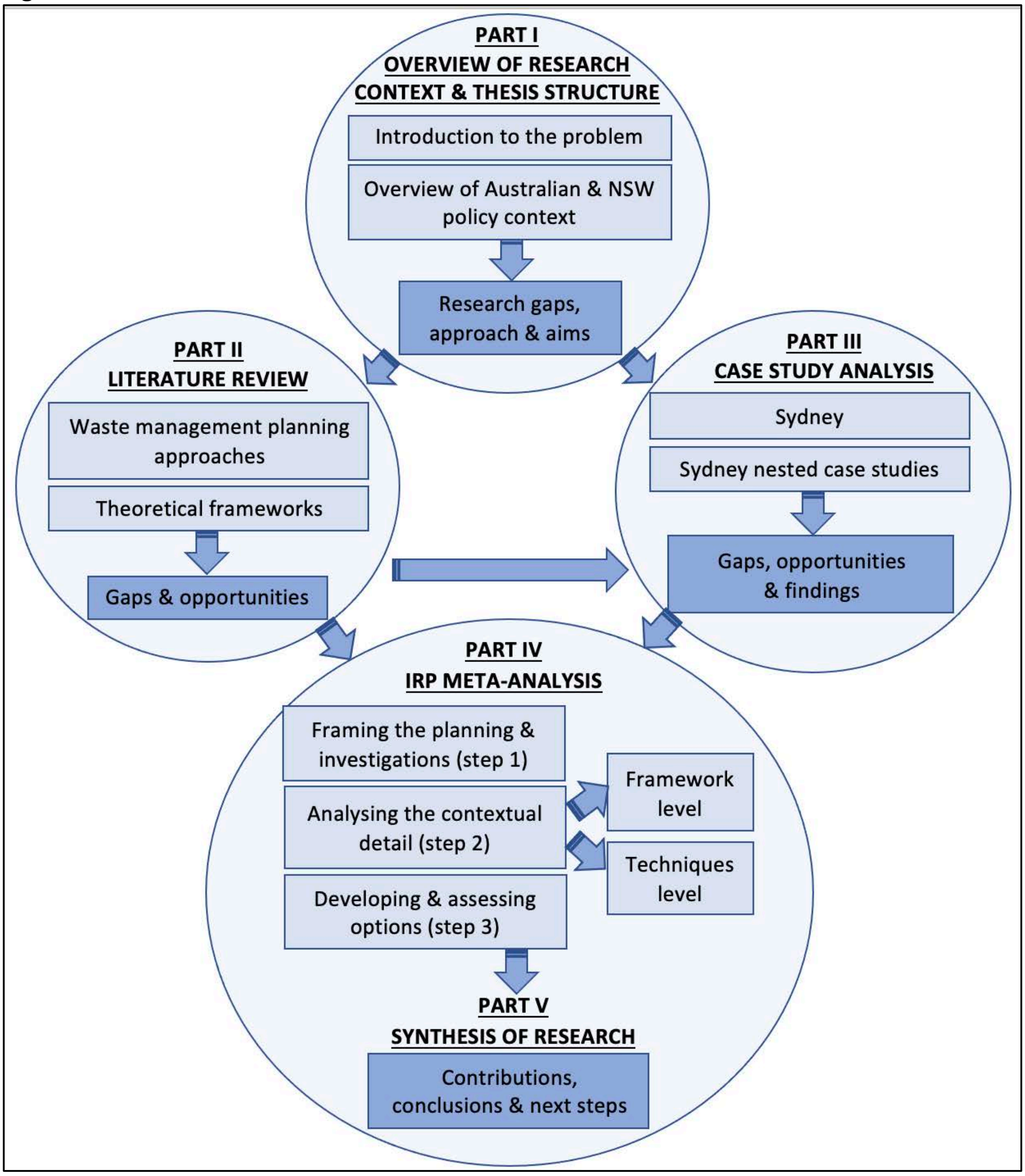
Methods used	**Thesis Parts & Sections**				
	I	**II**	**III**	**IV**	**V**
	1	**2 & 3**	**4 & 5**	**6 - 8**	**9**
academic and grey literature reviews	√	√	√	√	
document analysis	√	√	√	√	
policy analysis	√		√		
stakeholder analysis & liaison			√		
semi-structured interviews, thematic analysis and synthesis			√		
Workshops, thematic analysis and synthesis			√		
data collation and analysis	√		√		
modelling			√		
gap analysis	√	√	√	√	√
meta-analysis				√	
comparative analysis		√		√	
overall synthesis and reporting	√	√	√	√	√

More details on the methodology and methods used for each of the Sydney-based nested case studies are provided in Part III.

1.4 THESIS STRUCTURE

Figure 1.11 provides an outline of both the thesis overall methodology and structure, which is broken down into distinct 'Parts'.

Figure 1.11 – Outline of the thesis structure



Firstly, in Part I, I introduce and discuss the global food waste and broader UOW problem and associated international efforts to solve that problem. I then provide background on Australia and the rapidly shifting waste policy context in Australia and the largest state of NSW, which are providing both opportunities to deal with UOW management yet also potential unintended consequences. This raising the question of whether better insights into food and other broader UOW generation and management are needed together with the development of more nuanced context-specific solutions and structured planning, analysis and decision-making approaches beyond those currently used. I suggest the use of IRP, a practical planning and decision-making approach used in other essential services such as water and energy, yet only used to a limited extent in the waste industry, as a potential means to aid transition in the emerging UOW management sector. I then outline the overall aims, approach and structure of the thesis.

In Part II, I look into the literature of waste management planning and then theoretical frameworks. Firstly in Section 2.0, I provide a brief history of how waste management has evolved and how the waste hierarchy that has dominated waste management in recent decades has been overtaken by the circular economy. I then outline many of the commonly practiced planning and decision-making approaches used in waste management (which often search for an LTS 'silver bullet') and question whether these are appropriate for UOW due to its specific characteristics and growing complexity in the urban environment. I then summarise the issues, gaps and opportunities of commonly used waste management approaches and question if it may be useful to look at the planning and decision-making approaches used in more mature essential services industries, such as water and energy, which have already been in the process of transition. Such transition including more multi-scale, hybrid, socio-technical systems with the potential to better utilise resources and minimise LTS lock-in and adaptive management and innovation lock-out.

In Part II, Section 3.0, I go on to look at the literature on theoretical frameworks. I first introduce IRP, a practice-based planning, analysis and decision-making framework used extensively in the water and energy essential services sectors for decades, and its potential application in the emerging UOW management sector. I outline the history, key concepts and principles of IRP and illustrate how these can be translated to UOW management. I then introduce systems thinking and outline the strong theoretical linkage with IRP before introducing sustainability transitions, which, while founded on systems thinking, has additional perspectives that could be useful in UOW management. After providing details on the key concepts and methods from the three approaches I then suggest the opportunity of strengthening the practical IRP framework with the additional lenses of systems thinking and sustainability transitions. This combined perspective providing the opportunity to address many of the gaps and opportunities identified in Section 2.0, improve UOW management planning, analysis and decision-making beyond the current approaches used and assist in the advocated transition of UOW management to more sustainable practices.

In Part III, I draw from the gaps and opportunities identified in Parts I and II and focus on Sydney and the Sydney-based nested case studies. In Section 4.0 I provide more detailed context on Sydney and key characteristics that will impact UOW, including planning, analysis and decision-making. Using IRP concepts from Section 3.0, I look at the boundaries of the city used by various agencies and how inconsistencies complicate even basic statistics about the city. I then go through more detailed characteristics including population growth and urban densification and the growth in MUDs and mixed use/precincts which will affect UOW and forecasts. I also note the highly dated C&I data which makes it difficult to ascertain non-residential UOW generation and how the government supported organics waste programs and other smaller-scale interventions over the last decade, which are not registered, will likely affect overall UOW generation and potential savings. I also draw together data on other UOW streams such as wastewater biosolids, fats, oils and grease from grease traps and used cooking oils, and the lack of public knowledge, which limits cross-sectoral analysis on potential benefits and unintended consequences. The gaps and opportunities identified further highlight the need to improve Sydney based UOW data measurement, collation and analysis.

These gaps and opportunities are addressed, where feasible, by the Sydney-based nested case studies summarised in Section 5.0. Each case study filling industry knowledge gaps on both the UOW streams and potential innovative socio-technical solutions available. The three Sydney-based nested case studies, at the mixed use/precinct, sub-LGA and LGA scales, using a combination of IRP, systems thinking and sustainability transitions methods. In this Section I provide an overview of the case studies and how they were developed. I then give details of the collaborators involved, the aims of the studies, the funders motivations and main outputs. I also summarise the methodology for each study, key methods used, overall findings and my specific contributions. Each case study provides new insights not previously available and demonstrate the use of IRP, systems thinking and sustainability transitions concepts and methods, not previously used in UOW management.

In Part IV, I draw together the gaps and opportunities identified in Part II (Sections 2.0 and 3.0) and the Sydney-based nested case studies summarised in Part III (Sections 4.0 and 5.0) to conduct a meta-analysis using water IRP as a heuristic. This to help think through and demonstrate at both a conceptual and practical methods level how IRP could fill some of the identified gaps and opportunities in waste management planning. These sections of the thesis aiming to specifically advance UOW management planning, analysis and decision-making but also water IRP practice as well, where applicable. The gaps and opportunities discussed within Sections 6.0, 7.0 and 8.0 relating specifically to Steps 1, 2 and 3 within the IRP framework. Within each of Section 6.0, 7.0 and 8.0 I: (i) reiterate the UOW key gaps and opportunities identified and how they manifest in the emerging complex UOW management sector in Sydney and Australia; (ii) conceptualise at a high level how IRP, potentially strengthened by systems thinking and/or sustainability transitions, might be used in UOW to fill those specific gaps and opportunities using water IRP examples; (iii) demonstrate from the case studies the testing of various methods based on IRP and/or systems thinking and sustainability transitions that could fill the identified gaps and opportunities at a practical methods level; and finally (iv) discuss the potential application for UOW IRP and, in some cases, broader water IRP.

Finally in Part V I provide a synthesis of the research conducted, my contributions, conclusions and potential next steps. I also provide a summary table of the gaps and opportunities, IRP steps and potential novel methods to incorporate into practice and an outline of an UOW IRP framework.

The appendices focused on the Sydney-based case studies include:

- Appendix A – The Pyrmont-Ultimo Precinct (PUP) Scale Organics Management Scoping Study (Turner et al., 2017)
- Appendix B - Central Park Precinct Organics Management Feasibility Study (Turner et al., 2018)
- Appendix C - Organix19: Organics Waste Management in a Circular Economy. 9 & 10 May, 2019, Sydney (Turner et al., 2029)
- Appendix D (Confidential) - Organics Revolution: Planning for 2036 and beyond (Jazbec et al., 2020a)
- Appendix E - The options inventory (Turner, 2020) developed as part of the Jazbec et al. (2020a) IWC case study.

PART II:

LITERATURE REVIEW THEORY & PRACTICE

2 WASTE MANAGEMENT PLANNING APPROACHES – PAST, PRESENT & EMERGING

In this Section I provide a brief history of waste management. I highlight how the waste hierarchy has been dominant in guiding waste management in recent decades but is now being complemented, and in some cases overtaken, by the circular economy. I also outline many of the commonly practiced planning and decision-making approaches used in waste management. However, due to the specific characteristics of food and other UOW, such as perishability and nutrient and bioenergy potential, together with its growing complexity in the urban environment, I question whether applying these more common approaches (which often search for an LTS 'silver bullet'), are the most appropriate. I then summarise the issues, gaps and opportunities of the approaches and question whether it may be more useful, despite the plethora of approaches already available, to look at the planning and decision-making used in more mature essential services industries, such as water and energy. Such industries have already been in the process of transition to more multi-scale, hybrid, socio-technical systems with the potential to better utilise resources and minimise LTS lock-in and adaptive management and innovation lock-out.

2.1 A BRIEF HISTORY OF WASTE

Over millennia, anthropogenic waste has been generated and subsequently '*managed*' in various ways from dumping into wetlands, rivers, the sea, pits or mounds outside settlements through to various forms of reuse, recycling, composting, digestion, destruction and incineration (Williams, 2015a). As human settlements have grown through history, so too has the per person waste volume as well as the diversity of materials. With settlements initially relatively low density and the waste produced mainly ash from fires and human and animal biodegradable products, the materials produced were reused, collected, dumped or assimilated into the local environment to varying extents (Williams, 2015a). However, with the advent of the Industrial Revolution in the mid-1700s, things began to change.

In the mid-1700s, modern medicine was born and access to raw materials and trade stimulated invention and new mechanised manufacturing processes in Europe (Williams, 2015a). This resulted in both the urban population and associated waste generated growing rapidly in the West (Williams, 2015a). According to Williams (2015a) and Herbert (2007), in densely populated cities such as London this led to a build-up of waste and associated stench in the streets and ad hoc forms of collection, management and re-use and recycling of all kinds of materials. This resulted in the recording of the first waste management strategy being developed in 1751, led by Corbyn Morris, which advocated city-wide collection and conveyance of wastes to sites outside London and the use of materials for various purposes such as brick-making and soil conditioning (Williams, 2015a; Herbert, 2007).

By 1800, London had an organised system, and the idea had spread to other cities (Herbert, 2007). However, due to poor ongoing sanitation issues, with the river Thames essentially an open sewer, widespread disease prevailed in built-up areas, causing a number of severe public health epidemics (Williams, 2015a; Herbert, 2007). In the mid-1800s, social reformer Edwin Chadwick observed the poor living conditions and health of the working people and a combination of his reports and Victorian health and air pollution legislation led to the establishment of government departments (municipal authorities) to collect and dispose of both sewage and solid waste (Williams, 2015a; Herbert, 2007). Effectively, this led to the emergence of LTS for the separate collection and treatment of sewage and solid waste management.

By the late 1800s, the UK and Germany led the development of destructors/incinerators with the aim of not only reducing waste volumes, but in some cases, the generation of energy (Pichtel, 2014). Destructors were the main disposal option of choice for large cities such as London, although barging of waste along the Thames to tips continued and uncontrolled dumping and disposal to land and sea in other areas without destructors was often employed (Herbert, 2007). During the early 1900s, destructors were not replaced as uncontrolled tipping was cheaper, but by the 1930s and 40s, a new generation of separation and incineration plants was born and helped play an important role during World War II. Salvaging and recycling became a key practice during the war and post-war period, including the communal collection of food waste for pig feed in the UK (Herbert, 2007). However, by the 1950s, economic growth and greater access to food and material possessions again resulted in an increase in urban waste quantities and diversity, with landfill dominating disposal options during the post-war period (Herbert, 2007; Giusti, 2009). This was the case until the environmental movement of the 1970s and 80s began to shift European methods of management, although landfill still dominated until the end of the 20th century (OECD, n.d.).

In the 1800s, the US similarly suffered from waste build-up, poor sanitation and disease with water and human waste removal prioritised. Solid waste management removal received attention later in the late 1800s and early 1900s when materials were collected and put in open pits and frequently burned (Williams, 2015). According to Pichtel (2014), by the late 1800s, the US attempted incineration similar to the UK and Germany but with less success, with over half the first 180 systems abandoned. Although, after 1910, issues had been resolved and incinerators were widely used, with 600 of 700 US cities having such plants by the 1940s. By the 1960s, many large cities incinerated waste within apartment blocks, but because the wastes were unsorted, they burned at relatively low temperatures and were subsequently found to contribute to air pollution. By the 1970s, due to public concern, new emissions standards requiring retrofitting of air pollution control devices on older incinerators and the fact that incinerators were more expensive and technology intensive than their landfill counterpart, 100 large plants were closed. Although, due to the energy crisis of the 1970s, there was a resurgence in the interest of waste-to-energy plants and refuse-derived fuel systems. This combined with the ongoing closure of sanitary landfill across the US saw a significant increase in waste-to-energy plants over the 1980s and 90s (Pichtel, 2014). However today, landfill still dominates (OECD, n.d.).

In Asia, prior to World War II, again predominantly due to disease, countries such as Japan initially focused on public sanitation and then solid waste management disposal (Williams, 2015). However, due to limited space for landfills, laws forced the use of incineration from the 1930s. During World War II almost all infrastructure was destroyed, resulting in Japan rebuilding its systems, which are now some of the most technologically advanced waste management systems in the world. Other Asian countries have responded to population growth, increased income and urbanisation in various ways including South Korea with almost zero food waste and one of the most sophisticated organics waste management practices in the world (Kim, 2022; Yoo et al., 2019), see Box 2. However, many countries across the globe still have little or no effective safe collection, treatment and disposal, with open dumping and uncontrolled burning and composting still prevalent (Williams, 2015).

Throughout recent history, waste management policy, planning and decision-making has been affected by various core drivers such as public health issues, environmental protection, resource scarcity and value, climate change and public awareness and concern (Wilson, 2007). Although other drivers such as urbanisation and economic growth, cultural and socio-economic factors, politics and governance and institutional arrangements, as well as international influences and pressure have also played a role (Marshall & Farahbakhsh, 2013). Each region or jurisdiction has been affected by and responded to such drivers at different times according to their local context (Wilson, 2007; Marshall & Farahbakhsh, 2013). This has resulted in the spectrum of waste management practices we see today from highly sophisticated to barely functional, along with the wide range of associated approaches used to aid waste management analysis, planning and decision-making as discussed in the following sections. The management of waste, however, has overwhelmingly taken the form of collection, removal and treatment to help gain economies of scale and reduce potential impacts within urban environments. This approach amplifies the historical take-make-use-dispose linear model and associated LTS thinking.

Box 2 – South Korean world leading food waste management

In the 1970s and 80s when South Korea was relatively poor there was little food waste. As wealth increased, attitudes changed and urbanisation intensified in the subsequent decades, landfills began to reach their limits. This resulted in a series of waste policies in the late 1990s and banning organic waste to landfill in 2005 and food waste leachate to sea in 2013. Separation of food waste from general waste along with universal kerbside collection was also introduced in 2013 (Kim, 2022).

The 'pay as you trash' schemes introduced vary. Residents are given or required to buy various sizes of designated food waste bags (less than AUD 1.00 per plastic bag). When collected residents either: stick a chip or sticker (bought from a grocery store) on their bin with a garbage truck collecting the bins only if chip/sticker present; or when using centralised bins use a radio frequency identification (RFID) tag system where each household has a card that will open an RFID bin with a magnetic card reader which weighs their waste and then charges monthly (Turner et al., 2017).

South Korea now recycles virtually all of its food waste rising from just 2.6% in the mid 1990s to close to 100% today. The food waste collected recycled into biogas, animal feed or fertilizer (Kim 2022)

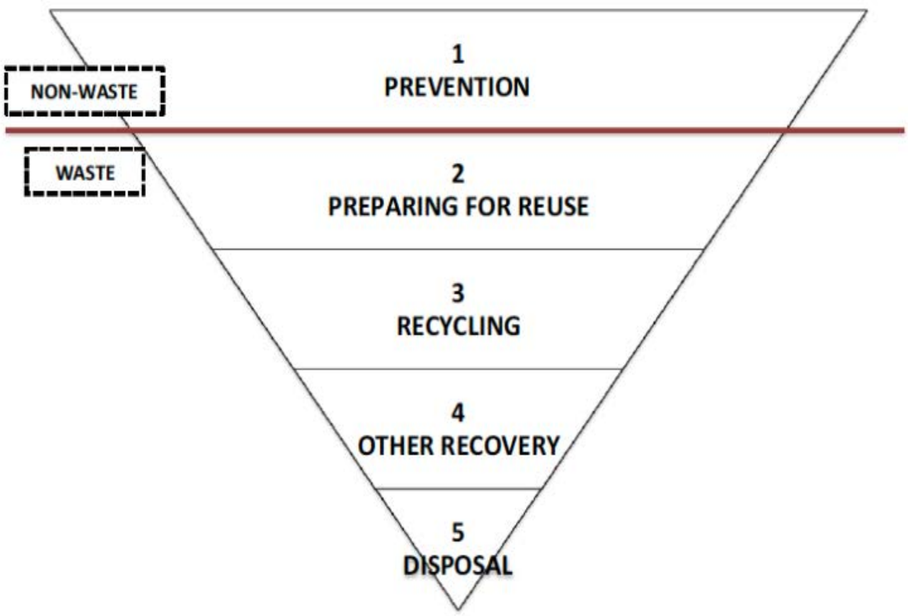
2.2 THE WASTE HIERARCHY & EMERGING CIRCULAR ECONOMY

2.2.1 THE WASTE HIERARCHY

In recent decades, waste management has been dominated and strongly guided by the waste hierarchy and equivalent 3Rs (reduce, re-use, recycle) often used in Asia. For example, in the US (US EPA, 2013), Europe (Council of the European Union, 2008; Van Ewijk & Stegemann, 2016; Eriksson et al., 2015; Williams, 2015b), Asia (Japanese Ministry of the Environment, 2005; Yoshida et al., 2007; Sakai, 2011) and Australia (CRC CARE, 2014; Giurco et al., 2015). First introduced in the Dutch Parliament in the late 1970s, the waste hierarchy was used in concert with innovation in technology and policy to successfully curb increasing levels of waste in the Netherlands and respond to widespread social and environmental concerns (Parto et al., 2007; Van Ewijk & Stegemann, 2016). Used for guidance in Europe for many years, it was finally introduced into EU legislation in 2008, as part of the Waste Framework Directive (Council of the European Union, 2008; Van Ewijk & Stegemann, 2016), with member states required to introduce it into national laws (Eriksson et al., 2015; Williams, 2015b).

The five-step process typically includes, in order of preference: prevention, preparing for re-use, recycling, other recovery (e.g. energy), and disposal to landfill, as shown in Figure 2.1. However, the exact wording and order varies across jurisdictions (Finnveden et al., 2005; Chang and Pires 2015; Redlingshöfer et al., 2020).

Figure 2.1 – The waste hierarchy



(Source: Gharfalkar et al., 2015. Republished with permission of Elsevier via CCC Rightslink)

Despite being legally binding in Europe since 2008, it has gradually been acknowledged that there is ambiguity and inconsistency in the meaning of the waste hierarchy (Gharfalkar et al., 2015). This ambiguity has led to subsequent interpretations, guidance notes and proposed advances from various organisations and scholars (DEFRA, 2011; WRAP, 2011; European Commission [EC], 2012; Eriksson et al., 2015), including new categories, such as in the 5Rs and 10Rs (Gharfalkar et al., 2015; Crammer, 2017).

In addition, although commonly used and recognised as a useful "mental checklist" (DOE, 1995, as cited in McDougall et al., 2001, p.25) and "visual communication tool/guide" (PoA, 2008, 4.26), it has also been recognised that it falls short as a decision-making framework because it is "too simplistic" (Brisson, as cited in McDougall et al., 2001, p.25). This is mainly because it focuses primarily on narrow environmental objectives (CRC CARE, 2014; Papargyropoulou et al., 2014; Eriksson et al., 2015; Mourad, 2016) and does not deal with combinations of options, costs or different contexts (McDougall et al., 2001). Thus requiring other tools such as CBA and LCA to assist decision-making (Council of the European Union, 2008; Gharfalkar et al., 2015; Van Ewijk & Stegemann, 2016), with LCA required in Europe as a scientifically robust method to justify deviating from the waste hierarchy when considering environmental impacts of different options (Brancoli & Bolton, 2019).

As part of the most recent Waste Framework Directive review in 2017–18, the Directive now includes numerous changes as part of the Circular Economy Package. These changes embrace the more recent thinking around circular economy principles (see Section 2.2.3 below) and include higher recycling targets and obligatory biowaste separation by 2023 (EEB, n.d.). These policy changes significantly shift how the large food and other UOW component of waste will be managed in Europe, forcing the need to incorporate new circular economy objectives in planning and decision-making beyond those of the historical use of the waste hierarchy. Although, the circular economy definitions, boundaries and practices need to evolve (Merli et al., 2018) in much the same way as the application of the waste hierarchy has had to.

These shifts in Europe from a focus on the traditional waste hierarchy to incorporation of circular economy principles has been observed in Australia in recent years with the gradual embedding of such principles and associated lexicon in Australian waste management policy (refer to Section 1.2 and Table 1.1).

2.2.2 THE FOOD WASTE HIERARCHY

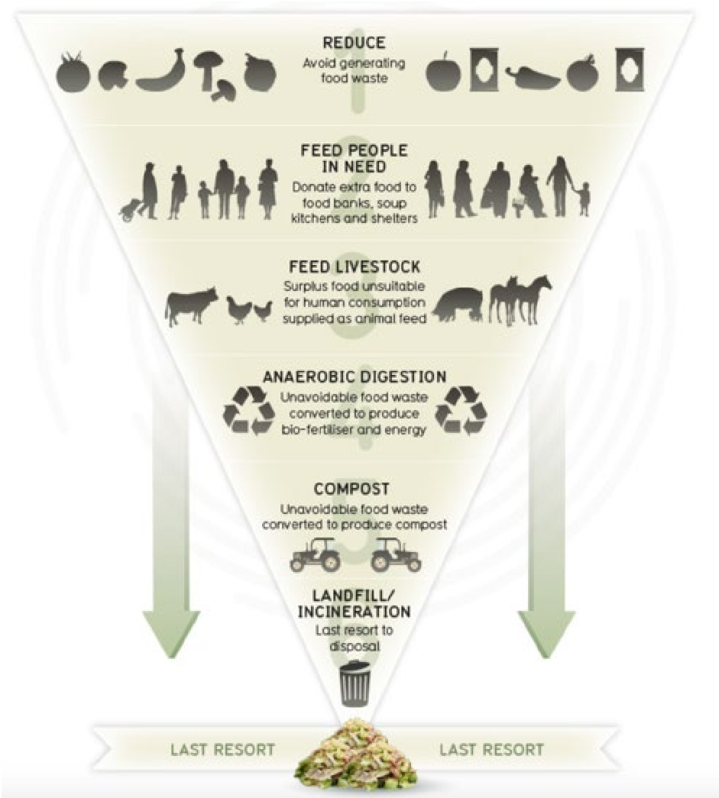
Food waste has unique characteristics, from its temporal quality (e.g. perishability) and associated potential avoidance options (e.g. used by humans or animals depending on perishability) (Garcia-Garcia et al., 2015) to its high variability in terms of nutrient and bioenergy potential (Al Seadi et al., 2008). Hence, in recognition of these complex characteristics and the growing global concern about food waste, the waste hierarchy has been adapted for food waste (WRAP, n.d.; USA EPA, n.d.; CoA, 2017; Papargyropoulou et al., 2014; Garcia-Garcia et al., 2015). The food waste hierarchy, in some of the latest examples, is now also linked with the circular economy (Teigiserova et al., 2020). Many of the original food waste hierarchy examples likely stem from the Moerman's Ladder (from the Netherlands) and were developed within the last decade (Government of Netherlands, 2014) in parallel to the circular economy, which specifically separates out the biological cycle from that of the non-biological cycle (EMF, 2013). See Section 2.2.3 below for details on the circular economy.

Figure 2.2 provides examples of the food waste hierarchy from (a) the UK and (b) the US, with the latter highlighting the importance of context and scale of application, as similarly discussed by Mourad (2016). This is seemingly missing in most waste hierarchy representations due to the waste hierarchy's inherent graphical simplification. Also, as with the original waste hierarchy (Redlingshöfer et al., 2020), there is inconsistency in the order of options in various examples, particularly with respect to composting and valorisation associated with AD for energy recovery. In most standard representations of the waste hierarchy, AD appears on a par with but often below composting, despite its dual benefit of both nutrient and energy recovery (Jazbec & Turner, 2018; Jazbec et al., 2020c).

Even with the food waste hierarchy's more detailed consideration of the specific characteristics of food waste, there is debate about whether it is adequately achieving sustainable outcomes. Hence the need to further examine it and alternative decision-making processes to help achieve such outcomes (Garcia-Garcia et al., 2015; Mourad, 2016; Redlinshofer et al., 2020). Mourad (2016) suggested that while the food waste hierarchy identifies preferences in the environmental perspective, there are social and economic 'hierarchies' competing with the traditional environmentally focused waste hierarchy, which have an alternative preferential order of solutions based on the objectives of those alternative hierarchies, as shown in Figure 2.3. This observation illustrates the growing number of stakeholders involved in food waste, their differing objectives and motivations, and a need to broaden the objectives and sustainability criteria in decision-making to account for the multiple stakeholders involved. This need is even more pressing when considering not just food waste but the other organic waste streams in urban environments, from garden organics to fats, oils and grease in grease traps generated and managed by diverse stakeholders. Such waste streams can, for example, have very different nutrient and bioenergy potential and thus useful recovery mechanisms and values for those stakeholders. These broader UOW streams have received little attention to date in the waste management industry compared to food waste, likely in part due to their fragmented and siloed management.

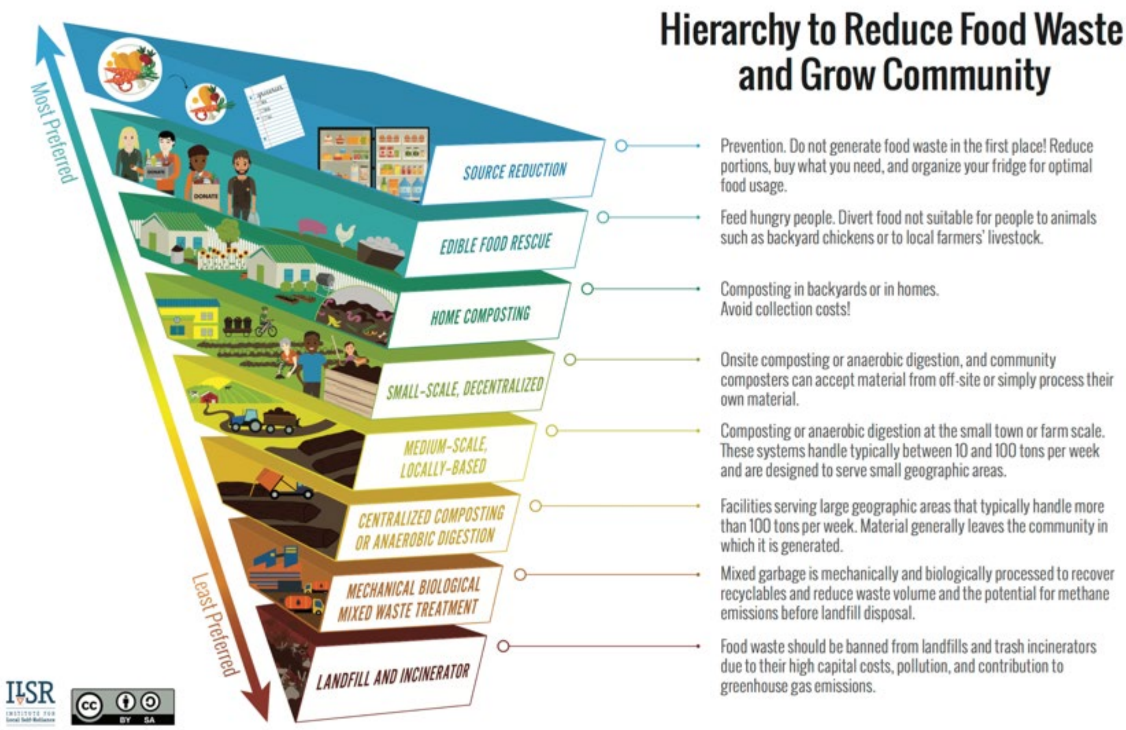
Figure 2.2 – Examples of the food waste hierarchy

(a) – UK



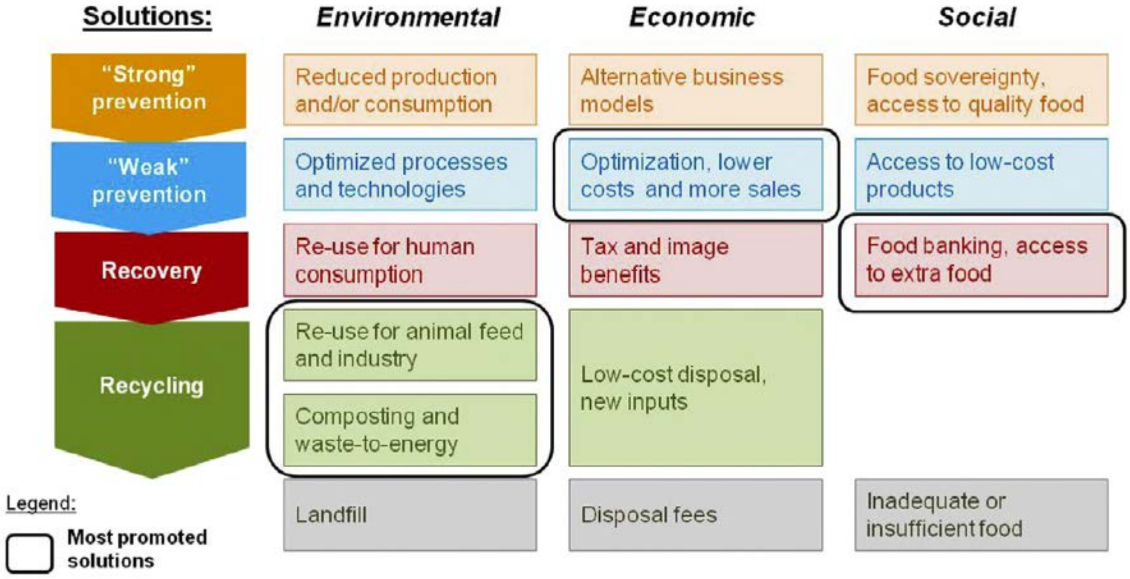
(Source: Vision2020, n.d.)

(b) – US



(Source: ILSR, n.d.)

Figure 2.3 – Competing food waste hierarchies



(Source: Mourad, 2016. Republished with permission by Elsevier via CCC)

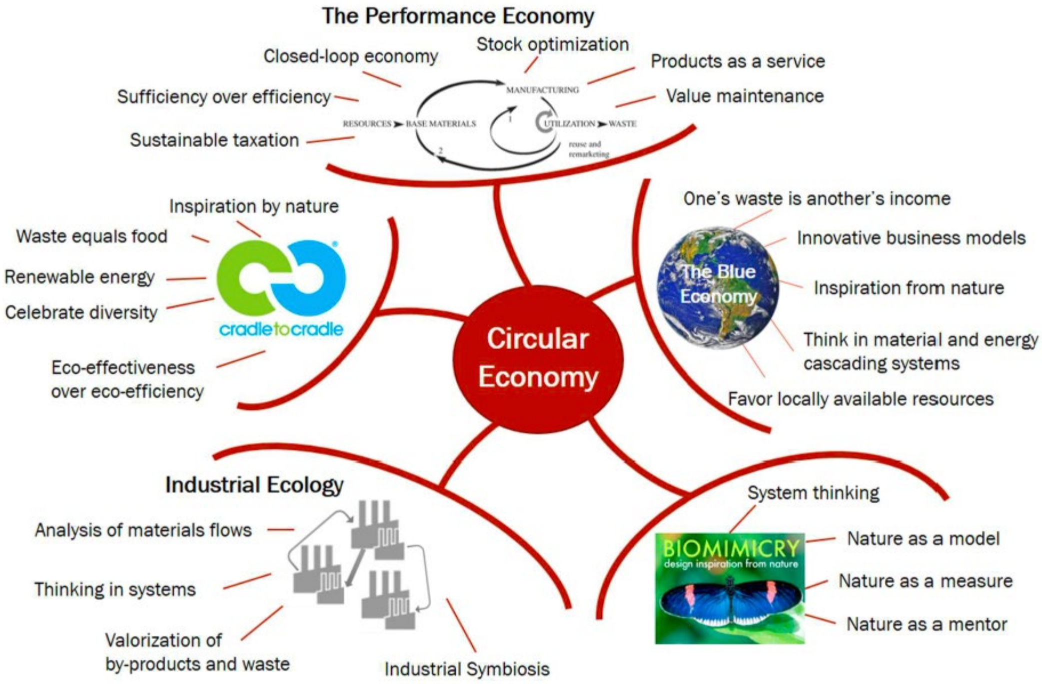
There is other evidence of the waste hierarchy not performing as perhaps it was intended. A review by Redlingshöfer et al. (2020) of recent food waste hierarchy studies found that despite the waste hierarchy and food waste hierarchy prioritising avoidance, such avoidance is under-represented in the literature, and that more emphasis is often placed on recycling and re-use options. This is supported by Mourad (2016). According to Hultman and Corvellec (2012), this could in part be due to the shift in narrative in Europe from waste as a 'problem' to that of a 'resource', as highlighted by the circular economy, but resulting in disincentives to reduce consumption. Redlingshöfer et al. (2020) question whether such narrative suggests consumption is no longer an issue and that food waste can be beneficially used (e.g. producing nutrients through composting and additional energy through AD). This is in addition to other barriers such as the waste management industry's traditional focus on removing, treating and disposing of waste, rather than trying to avoid it (Redlingshöfer et al., 2020) and associated LTS thinking. This focus is currently playing out in Australia with the drive for FOGO collection and treatment to achieve landfill avoidance targets and new national and NSW policy focusing more on 'avoidance from landfill' and 'recycling' rather than 'avoidance' per se. Such mixed messaging and counterintuitive consequences of policy highlighting the need for more nuanced direction and decision-making around avoidance beyond that of the waste hierarchy.

2.2.3 THE CIRCULAR ECONOMY

Over the last decade, the concept of the circular economy has emerged, as seen in Europe and many other jurisdictions. This is in response to the serious impacts of the prevailing linear economy practice of take-make-use-dispose and associated LTS to manage the materials produced. The circular economy is gaining traction as a companion guiding approach in waste management policy direction, as found in Europe and now more recently in countries such as Australia. Section 1.2 discusses how the profile of the circular economy has risen in the Australian policy context over the last five or so years.

While the term 'circular economy' is relatively new, it builds on several well-established aligned sets of concepts developed since the 1970s, such as Regenerative Design, Performance Economy, Industrial Ecology, Cleaner Production, Cradle to Cradle, Natural Capitalism, Biomimicry and the Blue Economy (EMF, 2013; Korse, 2015; Geissdoerfer et al., 2017) as shown in Figure 2.4. However, due to its eclectic origins it is recognised that it has been interpreted and implemented differently with the emphasis of the underlying principles and goals highly influenced by the motivations of those defining and implementing it (e.g. researchers, businesses, governments) (Korse, 2015; Geissdoerfer et al., 2017). A recent critical review by Walzberg et al. (2021) questions whether a new sustainability assessment method for the circular economy is needed considering the circular economy in and of itself does not necessarily ensure economic, social and environmental performance. Nor are the potential methods being used necessarily the most appropriate in making assessments of strategies aiming to transform the existing system towards circularity (Walzberg et al., 2021).

Figure 2.4 – Schools of thought influencing the circular economy



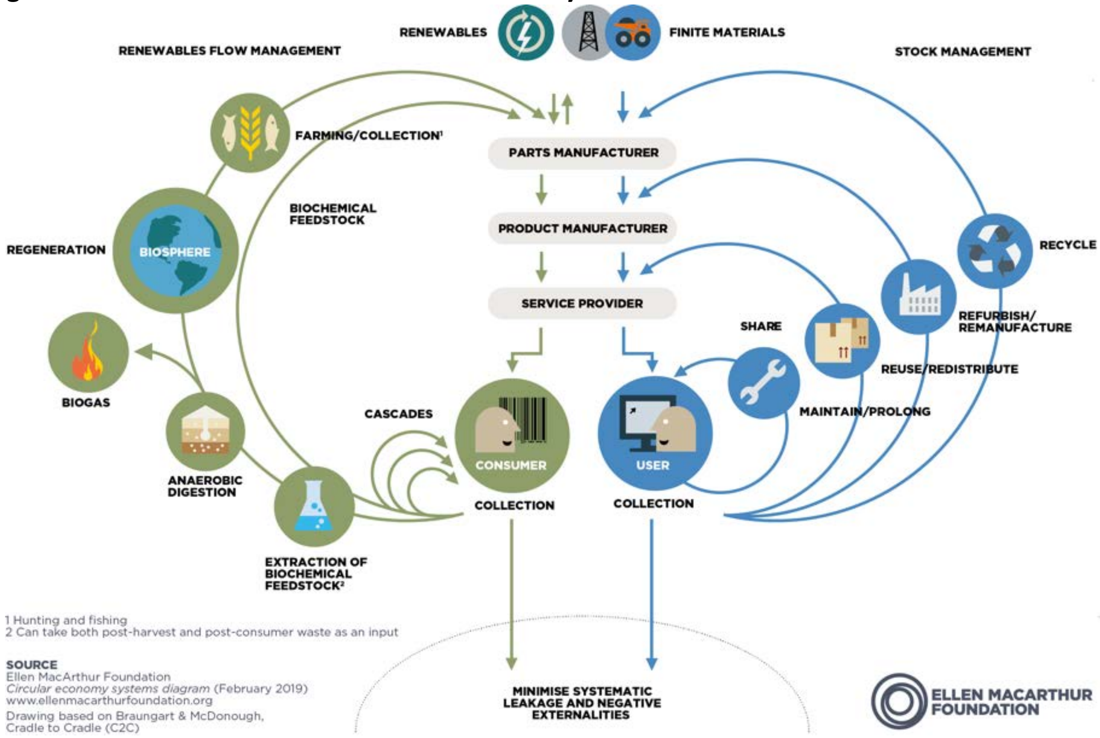
(Source: Wautelet, 2018. Reproduced with permission of author)

As a leading advocate for the circular economy, established in 2010 and responsible for many of the key formative publications on the subject, the UK-based Ellen MacArthur Foundation defines the circular economy, including key principles, as:

> Looking beyond the current take-make-dispose extractive industrial model, a circular economy aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is based on three principles: design out waste and pollution; keep products and materials in use; and regenerate natural systems. (EMF, n.d.)

Figure 2.5 is the EMF original visualisation of the circular economy. Importantly, it separates out the biological cycle and the many opportunities to extract value from such materials, including biochemicals and bioenergy. Within waste management, as identified in Section 1.1.2, food and other UOW is typically one of the largest components of waste. Hence, to embrace circular economy principles, as many waste management policies are highlighting, modern waste management will need to focus more attention on the food and other UOW component, its unique characteristics and critically how to make decisions on how to manage it. While the meaning and principles of the circular economy have been gradually aligning over recent years, the circular economy is still evolving as the complexity of moving away from a take-make-use-dispose linear model becomes more evident. The approach requires consolidation of its definitions, boundaries, principles and associated practices (Merli et al., 2018) and the gap on how the principles, which have multiple and often conflicting objectives, used in decision-making are filled.

Figure 2.5 - Visualisation of the circular economy



(Source: EMF, n.d.)

2.2.4 A NEED FOR ADDITIONAL FACTORS TO IMPROVE DECISION-MAKING

Sections 2.2.1 to 2.2.3 highlight that while the waste hierarchy has been used for decades and now the food waste hierarchy and circular economy have emerged to specifically better deal with food waste and the biological cycle, they are not necessarily performing and that broader factors need to be considered when making decisions on waste management. These factors need to go beyond the narrow environmental focus of the waste hierarchy (CRC CARE, 2014; Papargyropoulou et al., 2014; Eriksson et al., 2015; Mourad, 2016) and include broader environmental and social and economic factors (Mourad, 2016). They also need to go beyond those factors highlighted by the circular economy which in and of itself does not necessarily ensure sustainability performance (Walzberg et al., 2021). The waste hierarchy is acknowledged as requiring support by other assessment approaches such as LCA (Gharfalkar et al., 2015; Van Ewijk & Stegemann, 2016). Similarly, the circular economy is acknowledged as having flaws and implementation bias (Korse, 2015; Geissdoerfer et al., 2017) and requires further work to fill the gap on how its principles can be practically used in decision-making (Merli et al., 2018) and move towards more sustainable outcomes.

2.3 CURRENT DOMINANT DECISION-MAKING APPROACHES

As identified, while the waste hierarchy has provided guidance on the preferential order of options implemented, it is often supported by other more detailed planning and decision-making frameworks and tools. The use of these complementary approaches is highly dependent on the scale of waste management solutions being considered, the number, the stage of planning and application, the organisation conducting the planning and decision-making and indeed, in some cases, the jurisdictional regulatory requirements or guidelines, which can often be prescriptive.

Historically, such frameworks and tools have been mainly dominated by three core approaches, namely, CBA, LCA and MCDA/M (Morrissey & Browne, 2004; Moutavtchi et al., 2010; Karmperis et al., 2013). Although, other approaches such as environmental risk assessment and environmental impact assessment have also been used or incorporated into the three main approaches (Morrissey & Browne, 2004; Allesch & Brunner, 2014) and CBA, LCA and MCDA have been used together in various combinations or with other approaches to overcome weaknesses in each approach used in isolation (Karmperis et al., 2013). A recent review by Asefi et al. (2020) builds on previous reviews by Morrissey and Browne (2004), Chang et al. (2011), Ghiani et al. (2014) and Bing et al. (2016) and highlight potential improvements that can be made by combining various approaches.

When looking at the literature on such approaches, frameworks and tools, there is often ambiguity in the language. For example, MCDA can at times be discussed as a particular technique to deal with multiple objectives within a broader decision-making framework, but at other times as an entire decision-making framework in and of itself. The summaries below cover many of the commonly used approaches, frameworks and models, in their broadest sense, acknowledging this ambiguity.

2.3.1 PERFORMANCE INDICATORS

In many jurisdictions, performance indicators are commonly used as a simple measure to help assess the potential ‘success’ of a waste management strategy or individual option. They are typically quantitative and assist in providing an indication of progress over time. Common indicators include the rate of landfill diversion (i.e. waste sent to landfill divided by the waste generated) and quantity of waste recovered for recycling (i.e. often calculated as the amount of waste directed to a recycling facility) (EPHC, 2010; Edwards, 2017). While such indicators are necessary to provide quantitative data for decision-makers and how options they are considering might achieve set policy objectives, they may not always provide an indication of the level of sustainability of an outcome, as in the case of the recycling indicator. For example, the efficiency of turning a material into a valuable resource. With the emergence of the circular economy, other indicators are increasingly being considered, such as maximising resource and energy recovery (Bartl, 2014; Gharfalkar et al., 2015; Park & Chertow, 2014). Hence, such indicators need to be considered carefully to measure features that pertain to a specific policy agenda and or strategy (Edwards, 2017), align with objectives (often multiple) and carefully take into consideration baseline shifts.

In addition, care needs to be taken when considering simple per capita or household indicators, as in the case of SUDs and MUDs, where the nuance of performance can be lost due to household characteristics such as occupancy rate or having a large garden or none at all. Such consideration is often missed in other essential services, such as water, where usage identified in simplistic litres per capita per day or per household per day, become meaningless when compared across jurisdictions by well-meaning comparative studies and associated reporting. This is because the figures can mask vastly different local contexts such as climate, seasonality, urban form, sub-sectors, cultures, alternative private resources or where underlying shifts in the efficiency of technology, avoidance of use or behaviour change may have taken place over time (Turner et al., 2010a, Turner et al., 2016). Hence the need for temporal observation of such figures along with, importantly, temporal observation of the 'context' and 'factors' affecting those figures, including policy interventions implemented.

2.3.2 COST BENEFIT ANALYSIS (CBA)

CBA is an approach widely used to inform public investment decisions. In Australia, it is the preferred decision framework at federal and state levels (Fane et al., 2011). CBA aims to determine if the benefits of a policy, project or program outweigh the costs and to what extent. It involves quantifying in monetary terms both the direct and indirect financial, social and environmental impacts of policies, projects or programs under investigation in a specified area. CBA seeks to find the net benefit or cost expressed in discounted net present-value terms and is often expressed as a benefit-cost ratio. Where the ratio is greater than 1.0, the benefits outweigh the costs resulting in a net benefit to society and the suggestion that the proposed intervention/s should be considered for implementation. While there will be societal winners and losers, CBA assumes (rightly or wrongly) that the government can redistribute the benefits so that everyone is better off (Fane et al., 2011).

The approach's strength is that it aims to compare interventions using a single dollar metric (Fane et al., 2011; Mukheibir & Mitchell, 2011). However, this is also considered a key limitation as it requires monetisation of social and environmental impacts that may be ethically and/or analytically difficult to do. Also, it often requires costly methods such as contingent valuation or willingness-to-pay studies (Mukheibir & Mitchell, 2011; Watson, 2016) or the use of such studies from other areas (benefit transfer) as a proxy that may not be suitable (Fane et al., 2011). However, without including externalities, the selective costs and benefits represented can skew the analysis.

As identified by Morrissey and Browne (2004), environmental decision-making often involves diverse stakeholders that are likely to have competing interests and diverse objectives, which CBA in isolation is ill-equipped to deal with. It also allows improvements in one problem dimension (costs) to compensate for deterioration in another (e.g. emissions) and effectively prioritises economic efficiency, while overriding environmental and social criteria (Morrissey & Browne, 2004). Mukheibir and Mitchell (2011) outline the key steps in a typical CBA, common pitfalls and ways to improve the process, such as the use of MCDA. Moutavtchi et al. (2010) assess a number of different integrated waste management models that incorporate CBA, addressing some of their benefits and shortcomings.

2.3.3 LIFE CYCLE ANALYSIS/ASSESSMENT (LCA)

Life cycle analysis, or perhaps the more commonly used term in recent years assessment (LCA), is a quantitative assessment tool. It was first developed to manage waste and energy impacts initially focusing on the life cycle of a single product or building material to assist in assessing its sustainability (Udo de Haes, 2002). There are a variety of definitions. The UN defines LCA as "a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle" (UNEP, 2009). The key steps include setting a clearly defined goal and scope, compiling a life cycle inventory of relevant material and energy inputs and outputs including pollutants of a product or service, evaluating the environmental impact associated with the inventory, and interpreting the results of the environmental impact in relation to the goal of the study (Joint Research Centre Institute for Environment and Sustainability [JRCIES], 2010; IOS, 2006).

Unlike many other decision-making assessment tools and frameworks, LCA aims to consider the whole life cycle of a product or service, not just one single process or stage. For example, it goes beyond just assessing the environmental impact of a new composting facility by considering the collection and transportation of the organic materials and end use of the compost produced. In so doing it limits shifting of the environmental burden from one process to another (JRCIES, 2010; Edwards, 2017). Guinee (2002) highlights another strength of LCA, that it can provide a fair and balanced comparison between alternative technologies that may operate differently but perform the same function (i.e. comparative assertion LCA studies). However, while the ideal LCA aims to cover the whole life cycle, many LCAs only consider parts of the life cycle (e.g. cradle to gate or gate to gate) and thus comparison between studies can be difficult. Another limitation is the lack of inventory data for specific waste types and treatments (Edwards, 2017). Data and assessments should be specific to the context or region being assessed.

In Australia, such databases are not as well established as in Europe or North America, meaning assessments may need to rely on less-relevant international data sources (Edwards 2017). Compiling data and life cycle inventories can be expensive and time consuming (Andrea Blengini, 2008; Gentil et al., 2010) and thus, prohibitive. Kaufman et al. (2010) suggest using life cycle thinking not necessarily a full LCA, and that the use of a life cycle metric enables more appropriate and efficient benchmarking of different waste management systems rather than the more common recycling rate performance metric. Edwards (2017) goes further into the details of LCAs and the multiple models that have been developed, which are highly country specific, and the lack of LCA use in food waste assessment of options. The gap in LCA data gradually being filled, in terms of the Australian context, through the AusLCI database first initiated through the AusAgLCI initiative (Eady et al., 2014), and partially filled by Edwards for food waste (Edwards, 2017; Edwards et al., 2017; 2018) and more recently by FIAL (2021) through compiling a national assessment of food waste and potential interventions for avoidance.

2.3.4 LIFE CYCLE COSTING (LCC)

Life cycle costing (LCC) helps to augment LCA with financial analysis, and similar to CBA, uses economic techniques such as monetisation of environmental impacts to help assess social welfare with the aim of identifying options that maximise net social benefit. It differs from CBA due to the broader systems analysis and functional unit focus of LCA (Edwards, 2017). Hunkeler et al. (2008) classifies LCC into three categories: conventional, environmental and societal; mainly differing in terms of perspective, the kinds of costs included and potential uses. Others have similarly adopted this classification as identified in De Mena et al. (2018).

While LCC has been used for various waste streams, it has had limited use in assessing food waste to date and lacks a common methodological approach and consideration of upstream opportunities such as avoidance (De Mena et al., 2018). De Mena et al. (2018) looks specifically at LCA and LCC in food waste, providing a literature review of current food waste applications, limitations and opportunities.

2.3.5 OTHER COSTING TYPES

While CBA is the most common waste management costing method and LCC is useful in assisting LCA, other costing approaches are used within frameworks and models, as discussed by Moutavtchi et al. (2010) and CRC CARE (2014). CBA seeks to identify the net cost of an option by quantifying all costs and benefits. On the other hand, cost effectiveness analysis (CEA) enables the comparison of various options, which aim to achieve a specified objective and is used to rank the options according to least (net) cost in achieving that specified outcome (Hanley & Spash, 1993; Fane et al., 2011). The costs of the options are in present-value terms and can, similar to CBA, include the net costs (total costs less total benefits of those benefits that can be monetised) (Fane et al., 2011). However, the monetisation of benefits is not necessary to enable the relative merits of various options to be compared with CEA, typically retaining benefits in natural or physical terms such as kilolitres ($/kL) for water or tonnes ($/t) for waste.

As not all benefits are monetised, proponents of CBA consider CEA as only a partial assessment of options and cannot help with deciding whether the underlying objective is worth investment, that is, a net benefit to society. However, when considering options (such as in water or waste management) a key objective of water security (or avoiding waste passing to landfill) has typically already been established through political, institutional and/or consultative processes (Fane et al., 2011). There are, however, multiple other objectives that also potentially need to be considered, such as peak water use and energy intensity of production for water or energy generation and nutrient recovery for waste management. These other objectives require additional methods to assist in ranking and prioritising various options or combinations of options, such as MCDA (refer to Section 2.3.6). Such MCDA methods are used in conjunction with CEA in various water IRP analysis examples (Turner et al., 2007; White et al., 2008).

Another commonly used method is full cost accounting (FCA). FCA has been defined in many ways (Bebbington & Gray, 2001), with a definition provided by the International Federation of

Accountants (IFAC) as "the commonly accepted term applied to the identification, evaluation and allocation of a combined and potentially complex set of conventional costs, environmental costs and social costs" (IFAC as cited in Bakshi, 2015, p.5). The US EPA promotes FCA tools for waste planning. It includes accounting for all costs (i.e. hidden, past and future, overhead, and indirect) associated with waste management (from generation to final point of disposal or processing) (Tellus Institute, 2000). WastePlan, a model developed for FCA, has been applied in numerous cities and contexts. However, a limitation of FCA (and many costing approaches) is the lack of consideration of the pre-consumption component of the production and consumption system, limiting consideration of avoidance and minimisation options (CRC CARE, 2014) with a tendency to put more focus on costs as opposed to consideration of benefits (Weng & Fujiwara 2011). Bakshi (2015) investigated FCA for waste management in Australia and conducted a detailed investigation of a NSW council, finding barriers to its use, which the development of the NSW EPA landfill cost calculator (n.d.-c) may have assisted in overcoming.

2.3.6 MULTI-CRITERIA DECISION ANALYSIS/MAKING (MCDA/M)

The terms MCDA/M are often used interchangeably. The perhaps broader and more common term used, MCDA, can be defined as "an umbrella term to describe a collection of formal approaches that seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter" (Belton & Steward, 2002, p2). Such decisions generally deal with complex problems or issues where the consequences may be substantial; the impacts are likely to be longer term and may affect many stakeholders, and mistakes may not be easily remedied (Belton & Steward, 2002).

MCDA/M are similar and stem from operations research, an analytical decision-making approach that emerged during the challenges of World War II (Ferreira et al., 2011), under the auspices of decision analysis (Keeney, 1982). However, while MCDM emerged from the US school of thought, MCDA emerged from Europe with less focus on analytical optimisation, which is considered a '*hard systems*' approach, and more on embracing '*soft systems*' concepts. Refer to Section 3.3 for further details.

According to Figueira et al. (2016), the official starting point of MCDA/M was the gathering of practitioners at a conference organised in the US in the early 1970s (Cochrane & Zeleny, 1973). It is now used for numerous applications such as military operations, healthcare, business, insurance, transport, resource management and energy planning, to name but a few, with considerable and growing diversity in the adoption of approaches, methods and models used.

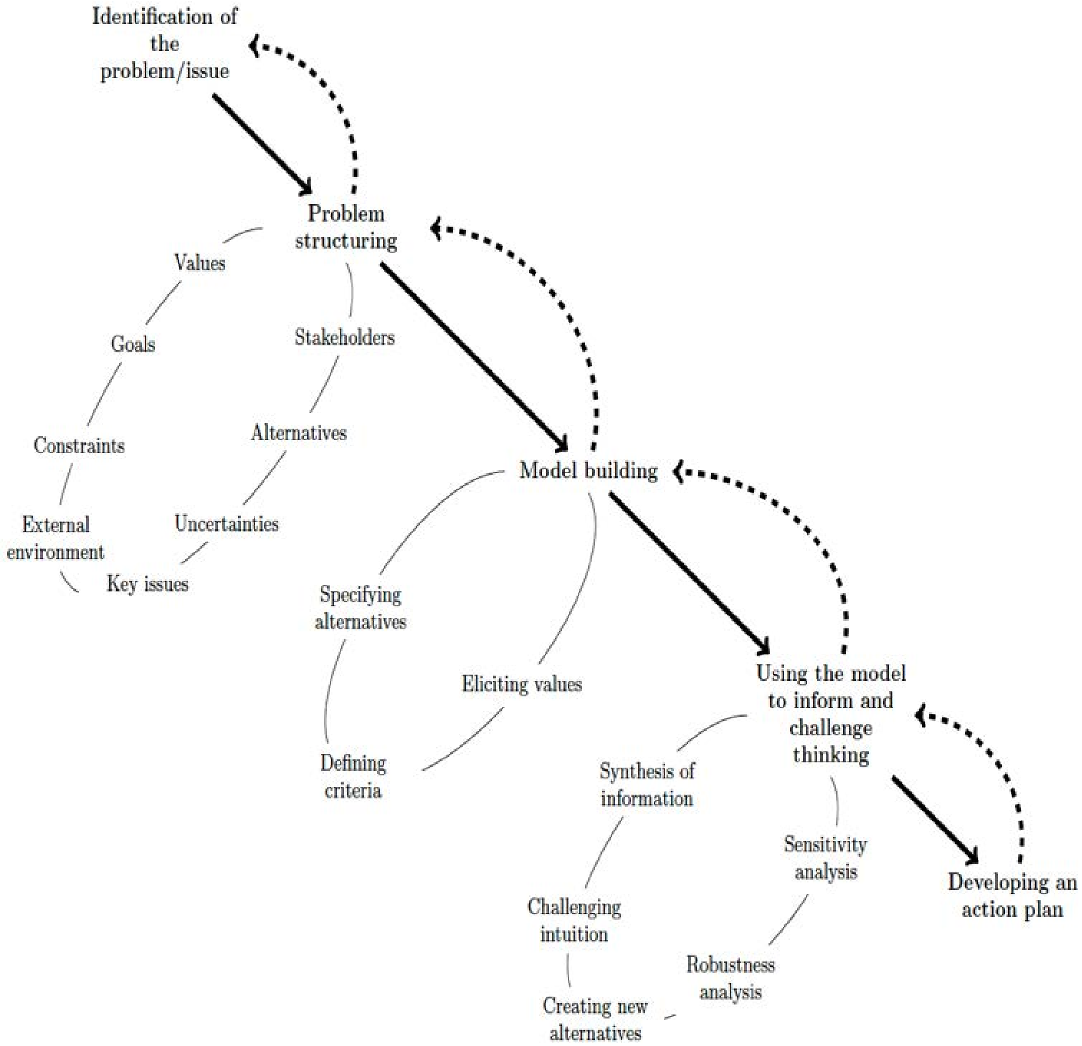
These include combinations of methods to help address identified weaknesses and increasingly complex decision-making situations (Velasquez & Hester, 2013; Marttunen et al., 2017) particularly with respect to uncertainty (Mardani et al., 2015 as cited in Marttunen et al., 2017).

MCDM is considered a sub-discipline or branch of operations research. Where operations research suggests dealing with a decision problem by first defining a single dimensional objective function (i.e. a cost index as in the case of CBA) and looking at solutions that optimise that objective function (Bana E Costa et al., 1997). MCDA, on the other hand, specifically aims to take into account multiple criteria, each representing a particular dimension of the problem being examined (Bana E Costa et al., 1997). MCDA aims to assist decision-makers to learn about a problem and the potential alternative from multiple perspectives. It aims to generate and consider multiple criteria, which are often conflicting, in a structured process to help conduct decision-making in a more robust, transparent and defensible way. It enables both quantitative and qualitative information to be incorporated and goes beyond optimising a single dimensional objective function, as in CBA, by allowing additional criteria to be assessed on an equal basis (Bana E Costa et al., 1997; Morrissey & Browne 2004). The central elements are simple, according to Figueira et al., (2016: pxxi):

> A finite or infinite set of actions (alternatives, solutions, courses of action), at least two criteria, and, obviously, at least one decision-maker. Given these basic elements, MCDA is an activity which helps making decisions mainly in terms of choosing, ranking, or sorting the actions.

There are many different MCDA methods used, such as utility and value theory approaches (MAUT, MAVT), outranking approaches (ELECTRE and PROMETHEE) and analytical hierarchy processes (TOPSIS, FUZZY AHP) (Antunes & Henriques, 2016). However, when considered at a framework level, MCDA basically seeks to provide a process to break a complex problem down into smaller components to help decision-makers analyse a situation in more depth and produce a meaningful solution based on defined criteria, values and preferences with the basic steps, as shown in Figure 2.6. These steps centring around problem identification and structuring, model building, and using the model and selecting an action plan (Belton & Stewart, 2002).

Figure 2.6 – The MCDA process



(Source: Belton & Stewart, 2002. Republished with permission of Springer Verlag London Ltd via PLS)

Depending on the specific method used, the sub-steps can vary significantly. Value focused thinking (Keeney, 1996) is a core concept often identified within MCDA approaches (Belton & Stewart, 2010). It is essentially where criteria are identified first in a decision-making process, then alternatives determined in light of those criteria. Thus enabling choice to be subsequently made. Advocates of value focused thinking argue that focusing on values first opens the door to opportunities rather than focusing on problems to be solved (Corner et al., 2001). However, those questioning the approach suggest that values may not be sufficiently clear in the early stages of decision-making to be able to do this and that values and criteria are typically formed out of experience with considering alternatives, effectively revealing hidden values and ultimately potential alternatives (March, 1988, Wright & Goodwin, 1999, as cited in Corner et al., 2001). Historically, such alternatives focused thinking, seen by some as competing with value focused thinking (Leon, 1999; Wright & Goodwin, 1999), has been the most common approach when exploring the literature (Nutt, 1993 as cited in Corner et al., 2001) with decision-makers often already having a well defined, discrete set of alternatives in mind (Corner et al., 2001). Corner et al. (2001) question both approaches and suggest a more iterative 'dynamic' approach may be better where alternatives help identify and define criteria and consideration of criteria help define alternatives. Many suggest that when such interactions are encouraged and explicitly incorporated, the result is more divergent and creative thinking (Volkema, 1983, Abualsamh et al., 1990, Taket & White, 1997 as cited in Corner et al., 2001).

Goulart Coelho et al. (2017) and Soltani et al. (2015), provide reviews on MCDA/M specifically for solid waste management. Coelho et al. (2017) found that such methods are in widespread use but narrowly applied, mainly to MSW LTS facility siting and associated treatment technology choice. Their recommendations include the need to incorporate more GIS/spatial data analysis when looking at problems, consider additional sector waste streams, and include more community focused stakeholder opinion as well as analytical improvements. The Soltani et al. (2015) review focused on the studies that consider multiple stakeholders in decision-making in MSW and found a proportional increase when compared to overall MCDA studies since the early 1990s (although Aesifi et al. [2020] suggest this is still lacking) with experts and governments/municipalities the most common participants. The review highlighted that where investment, collaboration and compromise are needed and competition unavoidable (i.e. many real-world situations), further study is needed to tackle these complex problems, including the potential for game theory (Nash, 1950) to enable stakeholders to observe multiple perspectives and preferences.

Babalola (2015) used MCDA as an individual analyst to investigate treatment options specifically for food waste and biodegradable waste management in Japan, examining sustainability criteria trade-offs using a pairwise comparison conducted through AHP. The analysis found that AD was the best treatment option regarding resource recovery when compared to other standard LTS options such as composting, landfill and incineration. Iacovidou and Voulvoulis (2018) developed a multi-criteria sustainability assessment framework to help compare two food waste management options (food waste disposal/InSinkErators discharging to sewer versus separately collected food waste co-digested with sewage sludge via AD) using a UK region as a case study (i.e. both LTS options). The MCDA-style assessment framework is useful for screening and sustainability assessment decision-making of options. The study emphasises the benefits of MCDA-style assessments to observe the cross-sectoral benefits of food waste AD co-digestion. It also emphasises the importance of understanding both the broad and detailed context of the system in question and stakeholders' preferences to define appropriate criteria for decision-making but the significant challenges associated with data availability and gaps to be able to obtain the holistic picture needed.

2.3.7 OTHER APPROACHES

Other approaches have been used and are emerging. While not listed as common in the literature, the triple bottom line (TBL) approach has been used and advocated in Australia for waste management. The term 'triple bottom line' was coined in 1994 and began to take off in the late 1990s/early 2000s (Elkington, 2004) and used in essential services assessment, such as water (NSW Government, 2019). There is no specific agreed definition. It has predominantly been used as an accounting framework for measuring and reporting business performance against not only financial but broader economic, social and environmental parameters. Elkington (2018) the original author identifies how the original intent of TBL was to go much further, that is, to create system change and push towards the transformation of capitalism. It has been used more broadly to guide the performance of organisations, industries, governments and communities by going beyond financial and economic dimensions to incorporate social and environmental dimensions, provide transparency, accountability and integration in planning and operations (ACT Government, 2011) but perhaps not to the extent Elkington had hoped (Elkington, 2018).

The ACT Government (2011) provides some background on how TBL has been used internationally and also specifically in Australia and how it has been subsequently side-lined due to the adoption of other sustainability frameworks. SKM (2003) and Lloyd Consulting (2010) both provide examples of TBL use in waste management options decision-making, incorporating organics options. Lloyd Consulting (2010) used the NSW Government-developed SWAP tool (NSW EPA, n.d.-d), which in a subsequent review by KPMG (2012), considered the use of the tool onerous even with its flexibility in terms of specific and default data. The NSW Department of Environment and Conservation (2007) also specifically developed a resource on TBL assessment of domestic food organics waste management for NSW councils.

A subsequent iteration has been the 'quadruple bottom line', which incorporates governance (Alibašić 2018). Similarly, the six capitals established by the International Integrated Reporting

Council (IIRC) aims to push the boundaries of accounting, representing tangibles such as financial, manufactured and natural capital together with intangibles such as intellectual, human and social/relationships (IIRC, 2013; Ardisa, 2017). Nogueira et al., (2020) expand the capitals further to eight, using systems thinking and circular economy principles. As with TBL, the capitals concept has been adapted beyond business reporting to assist in decision-making (Jazbec et al., 2020c).

Other interesting, yet less-common approaches, also include the use of game theory (Karmperis et al., 2013; Soltani et al., 2016; Palafox-Alcantar et al. 2020) and GIS (Bani et al., 2009; San Martin et al., 2017) with San Martin et al. (2017) combining GIS with the AHP MCDA technique for food waste valorisation. A recent review by Asefi et al. (2020), which builds on former framework and model reviews such as Morrissey and Browne (2004), specifically advocates the integration of GIS visualising techniques with system behaviour, spatial dynamics and solution approaches as a way to significantly assist in understanding waste management and complex urban systems. They also advocate incorporating game theory approaches to better involve stakeholders, including providing them with a range of solutions, and using integrated hybrid models that incorporate the best features of various approaches as a means of advancing models and improving decision-making.

2.4 EVOLUTION OF INTEGRATED AND SUSTAINABLE WASTE MANAGEMENT

In addition to the development and use of the various approaches, frameworks and models discussed above, used on their own and in combination, there has been an overarching movement of planning and decision-making based on '*integrated*' and '*sustainable*' waste management. According to Morrissey and Browne (2004) such terms did not really emerge until the 1990s despite the use of the concept 'integrated' first appearing with the term 'solid waste management' back in the mid-1970s with Murray et al. (1971) and Tobin and Myers (1974) (as cited in Wilson et al., 2013).

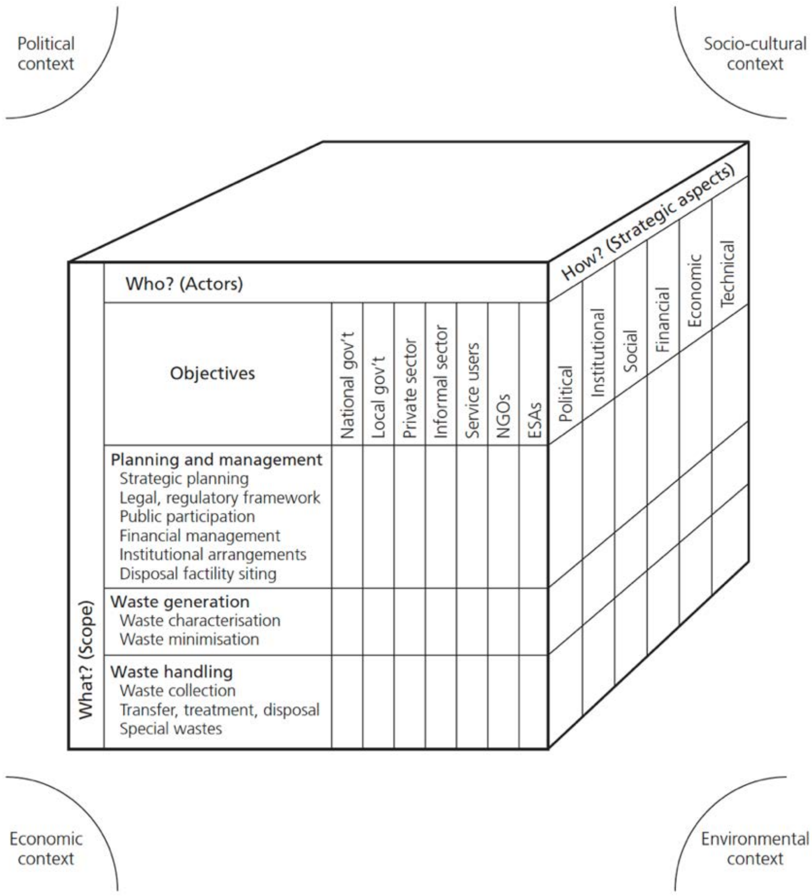
In the late 1960s and 1970s, the approaches and models being developed for waste management tended to focus on optimisation methods for specific problems such as transport routes (Truitt et al., 1969) and facility siting (Esmaili, 1972) often with narrow timescales, little recycling considered, limited options and a lack of consideration of multiple source generation (Berger et al., 1999). This making them difficult to use for long-term planning purposes (Sudhir et al., 1996). The approaches and models developed through the 1980s tended to expand the boundaries considered taking a broader systems view of MSW and the inter-relationships between the various components of waste management systems (MacDonald, 1996). This expanded view was, in part, likely due to the growing number of components within waste management systems beyond just landfill, such as recycling facilities, spurred on by the interest generated by the waste hierarchy that was gaining momentum at the time (refer to Section 2.2.1). Also during this time, improvements in computers enabled more of a focus on minimising costs of waste management (Gottinger, 1988; Englehardt, 1990) but used the traditional approaches of LTS collection and treatment with either LTS recycling or disposal (i.e. LTS optimisation).

The adoption of the term 'integrated' gradually grew during the 1990s and 2000s (Wilson et al., 2013). Although, the term 'integrated' used with 'waste management' was and still is used in various forms and is often interchangeable with 'sustainability,' despite these terms having a specific meaning and approach for various groups applying the terms (Seadon, 2010). McDougall et al. (2001, p15) defines "integrated waste management" as where "systems combine waste streams, waste collection, treatment and disposal methods, with the objective of achieving environmental benefits, economic optimization and societal acceptability" and "lead to a practical waste management system for any specific region". Although, Morrissey and Browne (2004) noted at that time (the beginning of the new millennium) that few approaches or models considered all three pillars of sustainability with social issues rarely covered, and unfortunately a review in 2020 by Asefi et al. (nearly two decades later), finding the social perspective still lacking.

There are typical features of integrated waste management or integrated solid waste management: it is implemented in developed countries, has a technical focus, has an aim to integrate individual elements into a more complete and/or regional system, uses computer tools to assist in that integration (Wilson et al., 2013), and advocates for the benefits of economies of scale for collective large-scale waste management (McDougall et al., 2001). Moutavtchi et al. (2010), Pires et al. (2011), Chang and Pires (2015) and Asefi et al. (2020) provide details of the significant number of approaches and models developed over the years mainly in the US, Canada and Europe, many with a focus on various systems analysis, assessment and engineering techniques with LCA, CBA and FCA playing key roles as well as MCDA.

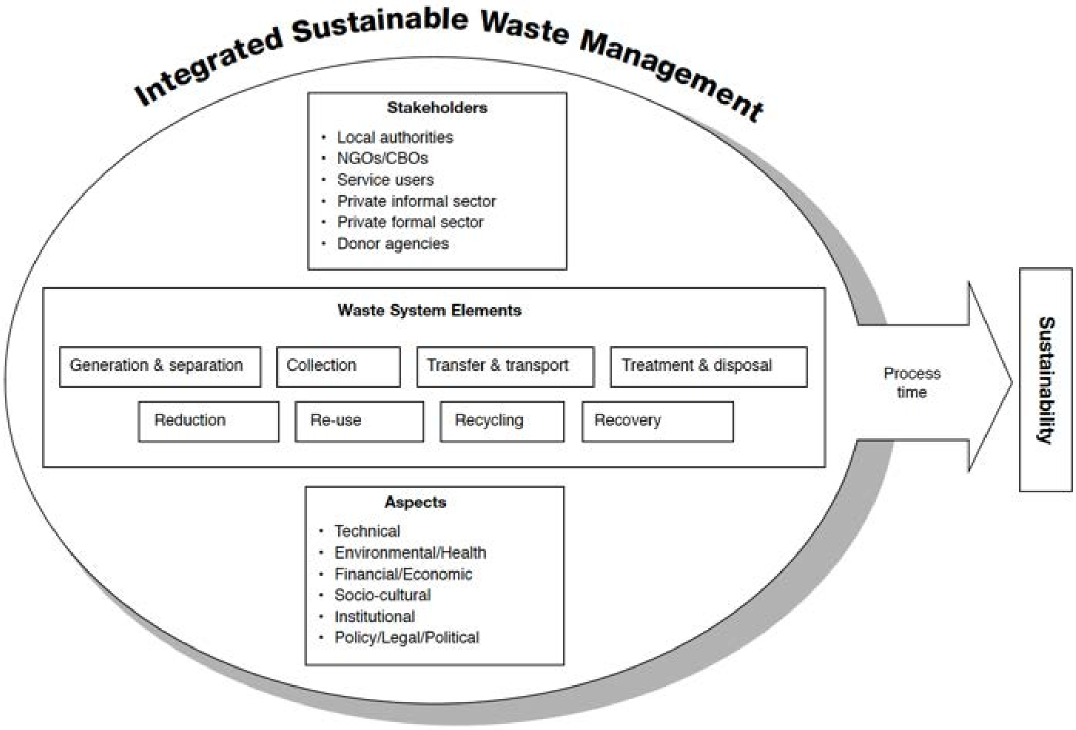
Also during the 1990s, international agencies and non-government organisations working in developing countries became frustrated with the waste management industry's focus on technical solutions (Wilson et al., 2013). Hence, they began collaborating (i.e. UNDP, UN-Habitat, World Bank and funders), leading to a workshop in 1995 and the development of a new framework that focused on integrated MSW management in low-income countries (Schubeler et al., 1996). These discussions formed the foundation of '*integrated sustainable waste management*' and associated frameworks (see Figure 2.7). Through the 2000s, this body of work was further developed and refined for developing countries with guiding documents and examples produced (Anschutz et al., 2004). This interpretation of integrated waste management explicitly focuses more on stakeholder engagement and participation, as distinct from consultation; disadvantaged groups; conservation of environmental resources; a wide range of conditions and issues; a participatory action research approach with stakeholders involved in the decision-making; and focus on the process itself not just the outputs (Anschutz et al., 2004).

Figure 2.7 – The integrated sustainable waste management framework
a – Initial version - (source Anschutz et al. 2004)



(Source: Schubeler et al., 1996)

b – Simplified version



(Source: Van de Klundert & Anschutz, 2001)

No matter the exact terminology, as identified by Kollikkathara et al. (2009), McDougall et al. (2001), Van de Klundert and Anschutz (2001) and Marshall and Farahbakhsh (2013), many of the principles of these approaches are similar, including:

- a balance between environmental effectiveness, social acceptability and economic affordability
- integration of interrelated waste management processes and components
- market orientation
- flexibility
- tailoring to specific community goals by incorporating stakeholders' perspectives and needs
- tailoring to a specific context including political, environmental, social, economic and legal/institutional factors
- combining the optimal combination of appropriate methods of prevention, reduction, recovery and disposal

Although, the extent to which each principle is brought to the fore seems to vary dependent on the bias of those instigating an investigation. Those using integrated waste management appear to have a tendency towards larger-scale, techno-centric solutions as opposed to those using integrated sustainable waste management reliant more on participatory processes and socio-centric solutions.

The steps to actually undertake sustainable and/or integrated waste management planning and decision-making vary and are not always obvious in the literature, but according to Chang and Pires (2015) often incorporate defining the problem and setting the boundary, identifying the objectives, producing alternatives, evaluating those alternatives, identifying a preferred solution, implementing and checking the performance. That is, a fairly generic adaptive management approach (Allen et al., 2011; Pahl-Wostl, 2007) resulting in a preferred engineering solution with varying reference to understanding the context, the types and use of data, forecasting approaches used and involvement of stakeholders within the process.

2.5 SUMMARY OF ISSUES, GAPS & OPPORTUNITIES

This Section has discussed how waste management has evolved in developed countries from backyard burning and dumping to centralised collection, re-use, recycling, landfilling and incineration. These shifts were triggered by major events and drivers over history, such as disease epidemics, public pressure over air pollution, social impacts and environmental concerns (Wilson, 2007). Such drivers, typically occurring at different times for different jurisdictions, marked major shifts in the waste management planning and decision-making approaches used as well as the waste management systems implemented.

With policy and other factors driving change in food waste (and now in some jurisdictions other UOW), waste management systems from the US to Europe to Asia and now Australia are becoming more complex in terms of the:

- **multiple and often conflicting objectives needing to be dealt with** – from improved public health, environmental protection and lowest cost solutions, through to reduced GHG impacts, increased energy generation and improved food security and access
- **growing number of diverse stakeholders generating and managing multiple UOW streams across built environments** – from individual households and small businesses to councils and large private businesses dealing with residential and C&I food waste, garden organics, used cooking oils, fats, oils and greases, wastewater and trade waste

- **number of innovative socio-technical solutions implemented and available at different scales** – from household menu planning, worm farming and on-site dehydrators to city-scale FOGO collection and industrial-scale composting and AD.

With policies still shifting, such as the relatively recent inclusion of high-level circular economy objectives, aspirations of net zero and a move towards separation of organic materials at source, waste management and specifically the UOW management system, will need to transition to more sustainable practices. It will also need to transition the planning and decision-making approaches used to determine what solutions are the most effective to implement in any given context. Such transitions will need to take into consideration multiple and changing drivers and the risk of LTS lock-in and adaptive management and innovation lock-out.

While there are a plethora of existing approaches, frameworks and models that have been used in waste management planning and decision-making, as indicated in Section 2.3, issues, gaps and opportunities remain. These gaps and opportunities amplified when considering the specific characteristics of the emerging food and other UOW sector. For example, as the ownership and management of assets becomes more complex in terms of business models and scales (i.e. reliance on multiple private service providers and stakeholders not just local governments) and as identified by Soltani et al. (2015), where investment, collaboration and compromise are needed and competition unavoidable. These issues, gaps and opportunities are summarised below.

2.5.1 DEALING WITH MULTIPLE AND OFTEN CONFLICTING OBJECTIVES & THE PILLARS OF SUSTAINABILITY

While the waste hierarchy has traditionally dominated waste management, it is widely acknowledged that it focuses on narrow environmental objectives, ignoring broader objectives such as the potential for energy generation and GHG reduction, as discussed in Section 2.2. These are of core relevance to UOW and its inter-connection with other industry sectors. Further, the waste hierarchy does not deal with economic and social objectives that often conflict with environmental objectives (Mourad, 2016) and thus require consideration of trade-offs. And in practice it is used more to focus on recycling, despite the primary objective being avoidance (Redlingshöfer et al., 2020), and generally considered far too simplistic (Brisson, 1997 as cited in McDougall et al. 2001, p.25). While the popular LCA approach, which is often used to augment the waste hierarchy, aims to provide a broader environmental perspective, it is data heavy, uses regionally specific databases (that are lacking in Australia), and requires additional costing approaches such as LCC (Edwards, 2017). CBA, also a popular approach, focuses on and optimises the economic objectives, often of limited options, and relies on monetisation of costs and benefits, which may be inappropriate to consider, not available or costly to obtain (Morrissey & Browne, 2004; Fane et al,. 2011; Mukheibir & Mitchell, 2011). And the circular economy, while growing in popularity, is still emerging in terms of definitions and practices (Merli et al., 2018; Walzberg et al., 2021). This is in part due to its eclectic heritage (refer to Section 2.2.3) and means it is highly influenced by the motivations of those defining and implementing it (Geissdoerfer et al., 2017; Korse, 2015).

Overall, despite various approaches being developed there is still a lack of adequate incorporation of economic, social and environmental perspectives when assessing solutions, nearly two decades after Morrissey and Browne (2004) first identified it as an issue in waste management, with the social perspective still appearing to be lacking in many approaches and models used (Asefi et al., 2020). Although, as identified by Soltani et al. (2015), there has been a proportional increase in considering multiple stakeholders in at least MSW MCDA decision-making, where perhaps councils have been forced or open to greater community engagement. There are also limited examples focusing specifically on the array of often conflicting objectives and sustainability criteria raised when considering food waste, a gap filled in part by authors such as Iacovidou and Voulvoulis (2018), and even less when considering broader UOW. MCDA provides the most promising approach to dealing with multiple objectives and setting of associated criteria for assessment, both as a broad framework or in combination with other approaches (Asefi et al., 2020). Although, in practice, MCDA can still be limiting due to its tendency to numerical complexity and consideration of objectives upfront before solutions, as advocated by value focused thinking central to MCDA. Thus, according to a review by Corner et al. (2001), limiting divergent creative thinking and missing objectives and criteria not initially obvious and potentially only elucidated when considering objectives/criteria and solutions dynamically.

An extension of this important observation, which appears to be missing from the current literature, is the need for iteration not only between objectives/criteria (value focused thinking) and potential alternatives (alternative focused thinking) but also the specific context being examined (what could be termed '*context focused thinking*'). Consideration of context is highlighted as important in both integrated and integrated sustainable waste management (refer to Section 2.4) and reiterated in recent reviews specifically for food waste (Mourad, 2016; Spang et al., 2019)

Hence, planning and decision-making processes that actively consider a broad set of **objectives** and associated **criteria** specific to the unique characteristics of food and other UOW and that incorporate **MCDA features** could significantly improve food and other UOW management outcomes. As could consideration of the **specific context** and an array of **potential solutions** in an **iterative** way (i.e. value-context-alternative focused thinking).

2.5.2 TAKING INTO CONSIDERATION THE DIVERSE STAKEHOLDERS & MULTIPLE UOW STREAMS BEING GENERATED & MANAGED ACROSS BUILT ENVIRONMENTS

Approaches such as LCA help to identify the various streams of waste being generated and managed in the built environment, depending on the boundary defined. However, the vast array of stakeholders generating and managing such waste are equally important when capturing a more fulsome appreciation of the socio-technical system being considered. Both the integrated waste management and integrated sustainable waste management approaches help bring this systems perspective, including observation of the various stakeholders involved in the various elements and processes along the supply chain (McDougall et al., 2001; Van de Klundert & Anschutz, 2001). However, the extent to which the currently fragmented UOW streams or associated stakeholders and their perspectives are meaningfully incorporated or engaged is highly variable and often narrow (i.e. council-managed MSW streams). While integrated sustainable waste management (Van de Klundert & Anschutz, 2001) used more in developing country contexts tends to focus more on incorporating stakeholders, their perspectives and goals within a planning and decision-making process, integrated waste management (McDougall et al., 2001) used more in developed countries appears to consider them less so, being more large-scale techno-centric (Wilson et al., 2013). With, as illustrated by Morrissey and Browne (2004) and now also Asefi et al. (2020), the social perspective generally receiving less attention in waste management decision-making approaches when compared to economic and environmental perspectives.

There will, of course, be a spectrum of private and publicly available examples of consideration of various UOW streams and inclusion of stakeholders and the social perspective. But with the growing number of stakeholders involved in food and other UOW generation and management in dense urban environments, there is a need for a more in-depth understanding of the various UOW streams being generated and managed by various stakeholders at various scales. For effective food and other UOW management going forward, this must also include consideration of stakeholders' values and motivations (Mourad, 2016) as well as control and influence, which are often highly influenced by the specific context in question (e.g. policy environment and policy/regulatory levers being used, city versus region, public versus private waste management situation).

Hence, planning and decision-making processes that incorporate a **broader and deeper socio-technical systems perspective** could significantly improve food and other UOW management outcomes. Especially those from integrated sustainable waste management that actively consider the diverse **stakeholders** involved in generating and managing UOW and their perspectives.

2.5.3 CONSIDERING DIVERSE SOCIO-TECHNICAL SOLUTIONS IMPLEMENTED & AVAILABLE AT DIFFERENT SCALES

Again, the waste hierarchy in terms of consideration of options, is acknowledged as too simplistic and does not effectively deal with combinations of options, costs or different contexts (McDougall et al., 2001), although the US food waste hierarchy depicted by ILSR (n.d) (see Figure 2.2) does highlight scale, which is typically lacking (Mourad, 2016). CBA traditionally considers the net benefit to society of a proposed intervention and whether it should be considered for implementation (Fane et al., 2011) but often for a single or narrow number of options. There are examples of LCA used in food waste in Australia (Edwards et al., 2018), and LCA with LCC and MCDA in Canada (Soltani et al., 2016), and MCDA in Japan (Babalola, 2015) and the UK (Iacovidou & Voulvoulis, 2018). Such examples are beginning to help illustrate the array of potential food waste, and in some cases, broader UOW streams solutions, scale and comparative costs and benefits, as highlighted as a gap by Spang et al. (2019). Again, MCDA shows promise in terms of a more fulsome assessment of solutions considered and compared.

However, compared to the spectrum of socio-technical solutions now available to manage UOW, such options assessments merely scratch the surface of what is now available. And when organics management options are considered in strategic documents, in Australia they often only represent a small component of the mix of options available within waste management and/or focus merely on a small number of options or bin sizes/collection timing for a narrow stream of UOW such as residential food waste and garden organics (ACT NoWaste, 2018; GHD, 2019; WSROC, 2017). This in part due to the jurisdictional and sectoral boundary of the councils conducting the assessments, fact that many of the strategies were developed before food waste, organics and the circular economy became so prominent in discourse (i.e. strategies were developed around 2017-18). Such narrow assessments of options and bias towards one size fits all/silver bullet thinking (Spang et al., 2019) having caused unintended consequences such as mixed waste organic outputs contamination in the past in Australia (See Box 1) and likely to result in suboptimal option selection and sustainability outcomes in the future. For example, the drive for national adoption of FOGO despite falling short on other cross sector policy objectives such as energy generation and GHG reduction, appearing to actually be one of the higher cost options (Jazbec et al., 2020a) and advocates ignoring concerns raised by many in the waste management industry in dense urban environments such as Sydney (LGNSW, 2017).

Hence, as advocated in the food waste review by Spang et al. (2019), we need to move away from one size fits all/silver bullet thinking and towards a broader **systems view,** which enables a **network of complementary options** that take into consideration **drivers and pressures** and obtain sufficient **contextual detail** to inform decisions despite the significant **gaps in data** currently being experienced. Going further, we also need to specifically take into account **innovation** on the horizon as part of a **futures perspective** to minimise **LTS lock-in** and **adaptive management and innovation lock-out**, considering the plethora of options becoming available. We also need to **preserve resources** more adequately, which although prioritised through **avoidance** language in the waste hierarchy, SDGs and circular economy, is still lacking (Mourad, 2016; Redlingshöfer et al., 2020). And finally, as highlighted by Asefi et al. (2020), we need to incorporate the **social perspective** and integrate approaches such as **GIS visualisation** techniques and even game theory to better understand complex waste management systems, **engage stakeholders** and improve decision-making.

2.5.4 SUMMARY GAPS & OPPORTUNTIES

Drawing these gaps and opportunities together, waste management and specifically the emerging food and other UOW management industry sector could be significantly improved by planning and decision-making approaches that better consider and/or incorporate various features identified in Table 2.1.

Table 2.1 – Key features to improve food and UOW planning and decision-making

Planning and decision-making that better consider and/or incorporate:
1. a broader & deeper **socio-technical systems perspective**
2. multiple & often conflicting **objectives** & **criteria** specifically relevant to UOW characteristics
3. the **broad context** of the jurisdiction being investigated & associated **drivers and pressures**
4. **cross-sectoral impacts** & **trade-offs**
5. the diverse **stakeholders** involved in generating & managing UOW to more effectively account for direct & indirect stakeholders & **social perspectives**
6. **MCDA features** that work through objectives & criteria, the specific context & an array of potential solutions **iteratively** (i.e. value-context-alternative focused thinking)
7. the **detailed context** of the jurisdiction to help inform decisions despite **data gaps**
8. a broader **network of complementary options** of varying scales
9. **preservation of resources/prioritisation of avoidance**
10. the risk of **LTS lock-in & adaptive management & innovation lock-out**
11. integration of **GIS/visualisation** techniques & even game theory to assist in better understanding complex waste management systems & **engage stakeholders** to improve decision-making

This does not mean ignoring what has been used before or necessarily using more complicated approaches, frameworks and models, indeed far from it. Rather, it suggests we acknowledge existing deficiencies in waste management approaches and perhaps look at other more mature essential services, such as water and energy, that have already begun the process of system transition to more sustainable resource management and effectively incorporated and considered many of the gaps and opportunities highlighted above. This despite an initial lack of data and information, as in the case of food and other UOW. By looking at such approaches, namely IRP and associated relevant concepts and practical methods, it is possible to consider whether IRP could be added to the mix of approaches used and specifically applied to the emerging UOW sector to help improve its planning and decision-making and associated transition to more sustainable waste management practices. IRP adds to the suite of approaches already available but with a unique practical perspective that could be augmented/strengthened by other additional complementary theoretical lenses such as systems thinking and sustainability transitions, each with their own specific qualities yet also aligned.

The IRP approach, along with systems thinking and sustainability transitions theories, is explored next in Section 3.0.

3 THEORETICAL FRAMEWORKS – A COMBINED VIEW

In this Section I introduce IRP, a practice-based planning, analysis and decision-making framework used extensively in water and energy essential services, and its potential application in the emerging UOW management sector. I first outline the history, key concepts and principles of IRP and illustrate how these can be translated to waste/UOW management. I then introduce systems thinking and outline the strong theoretical linkage with IRP before introducing sustainability transitions, which, while founded on systems thinking, has additional perspectives that could be useful in UOW management. After further discussion on the key concepts and methods from the three approaches I then suggest that by strengthening IRP with the additional lenses of systems thinking and sustainability transitions, this combination has the potential to address some of the gaps and opportunities in current waste management approaches identified in Table 2.1. Thereby improving UOW management planning, analysis and decision-making beyond the current methods used and assisting in its much-needed transition to more sustainable practices.

3.1 INTRODUCTION

As identified in Section 2.0, waste management planning and decision-making has evolved in recent years from the ubiquitous use of the simple waste hierarchy to the incorporation of other frameworks and tools such as LCA and MCDA. While such frameworks may be more complicated they may not necessarily be the most appropriate with respect to food and other UOW management planning and decision-making. As discussed in Section 2.5, this is in terms of the need to deal with the growing complexity of the emerging UOW management sector in the form of broad and often **conflicting objectives** (from reducing management costs, GHG emissions, environmental and social impacts to capturing increased bioenergy potential and nutrient recovery and extracting of high value chemicals). This is also in terms of the need to deal with the growing complexity associated with the number of **diverse stakeholders** generating and managing **multiple UOW streams** across built environments and the burgeoning array of innovative **socio-technical solutions** being implemented and on the horizon. As discussed in Section 2.5, UOW management planning, analysis and decision-making could be significantly improved by approaches that better deal with complexity and incorporate those features identified in Table 2.1.

IRP, a practical planning and decision-making framework that has been applied extensively in the water sector, appears to have had little application in the waste management industry (CRC CARE, 2014; Giurco et al., 2015) or specifically the new emerging UOW management sector (Turner & Fane, 2023). This is despite its demonstrated beneficial use in the energy and water essential services industries for decades (Turner & Fane, 2023) and assistance in transitioning those industries to more sustainable practices. This transition has included moving away from a reliance on LTS, which constrains adaptive management which is needed to respond to uncertainty, to more diverse hybrid systems. Such systems embrace a mix of complementary socio-technical solutions of varying scales specifically tailored to the context being considered. This importantly includes bringing to the fore efficiency/avoidance of resource use (Turner et al., 2010a; Turner et al., 2016), which, despite being key in waste management, appears to be still lagging, especially for food waste management (Redlingshöfer et al., 2020). Potential reasons for this lack of application of IRP in the waste and/or emerging UOW sector is discussed in Section 3.2.2.

IRP encompasses a practical adaptive management framework and a series of key concepts and methods that could be used in UOW management planning, analysis and decision-making to fill many of the gaps and opportunities identified. However, as discussed in the following sections, by also incorporating the lenses of system thinking and sustainability transitions theory and strengthening their linkage with the practical IRP approach, additional gaps and opportunities could be filled to help transition the UOW management sector to more sustainable practices.

3.2 INTEGRATED RESOURCE PLANNING (IRP)

3.2.1 HISTORY & DEVELOPMENT

This Section draws from and expands upon Turner and Fane (2023) that specifically looks at the history and development of IRP in the water and energy sectors and its linkage with systems thinking.

IRP has a long history of application in essential services/utility planning, which has evolved over several decades and assisted in paradigm shifts in water and energy planning, analysis and decision-making in various jurisdictions. In the US in the 1970s, it was recognised that utility systems planning focused primarily on the construction of large-scale, supply-side infrastructure, effectively ignoring efficiency opportunities. Concerned by this, in his ground breaking work, Lovins (1976) identified two paths the US could take in the face of the looming energy crisis. The first was a '*hard energy path*' in which the US could continue building high-cost, coal-fired and nuclear-powered plants with a high risk of social and environmental harm. The second was a '*soft energy path*', which embraced energy-efficient technologies and localised typically renewable sources, at a fraction of the cost and with significant long-term social and environmental benefits (Lovins, 1976).

This seminal work spurred a paradigm shift in utility planning. It highlighted the need to move away from concentrating solely on the reactive approach of supplying more and more energy through supply-side, large-scale measures, that is, LTS (Hughes & Coutard, 1996), and towards looking at the components or subsystems of how energy was being used and opportunities for end-use efficiency and more localised energy generation on the demand-side. During the late 1970s and early 1980s, Sant (1980) and Lovins et al. (1981) were also influential in championing the '*least cost*' approach (i.e. the emergence of least cost planning [LCP], the precursor to IRP), in which looking at total society cost and the demand-side of utility service provision was key.

As computing power improved and IRP/LCP gained traction, principles and practical methods for the approach were formed, including consideration of planning objectives and criteria, detailed demand forecasting and options analysis (Swisher et al., 1997; Tellus Institute, 2000). During this time IRP/LCP was also translated to the water industry in the US (Beecher et al., 1991), with the term '*soft water path*' coined by Gleick (2002). Similarly, methods were developed to better forecast water demand and design demand-side options and assess them against supply-side options (Dziegielewski et al., 1992; American Water Works Association [AWWA], 2007; 2017).

The approach was first used in the Australian water sector from around the mid-1990s in small regional towns (White 1998). By the late 1990s, it was used in Sydney, the largest city in Australia (White & Fane, 2002). Driven by the Millennium Drought that gripped Australia from the late 1990s for over a decade, IRP/LCP was used extensively for water planning in most major cities. This helped to aid Australia in becoming a leader in water efficiency, and advance the use of alternative supplies (i.e. rainwater tanks and wastewater recycling) and the application of IRP/LCP in urban water planning and drought management (Fane et al., 2011; Turner et al., 2010a; Turner et al., 2016). So much so that when California faced their worst drought on record, they turned to Australia, and one of their former students, for advice on insights from widespread implementation (Turner et al., 2016).

The terms LCP and IRP are often used interchangeably. Originally, LCP focused more on the lowest unit cost options (i.e. Sant [1980] and Lovins et al. [1981]), while IRP aimed to encapsulate a broader range of options and social and environmental factors (Swisher et al. 1997). According to Beecher et al. (1991) however, both consider a broad set of options and are open and transparent and thus interchangeable for most analytical purposes. Although, IRP places additional emphasis on integrating the institutions involved in planning and the many public policy issues they need to address (Beecher et al. 1991). In Australia, both terms have been used, with IRP more commonly used in recent years to infer the broader social and environmental issues, as well as costs.

IRP/LCP has also been applied to transport systems (White & Brennan, 2010) and waste management (CRC CARE, 2014) although to a limited extent (Giurco et al., 2015). While the conceptual development of IRP/LCP for planning these essential services is less progressed than that for energy or water, it is recognised as having significant potential (CRC CARE, 2014; Giurco et al., 2015; Turner & Fane, 2023).

3.2.2 KEY CONCEPTS/PRINCIPLES

From Turner et al. (2010a), key concepts/principles of IRP, based on water experience, centre around:

- focusing on service provision (i.e. water needed to provide the service of clean clothes, hygiene, pleasing gardens) rather than the commodity itself (i.e. water)
- conducting detailed demand disaggregation of each required service or end-use and forecasting for a specific context or area based on that detail
- considering a broad spectrum of demand- and supply-side options relevant to a specific context or area
- conducting balanced comparison of options, both demand- and supply-side, with consistent boundaries and assumptions
- being a participatory process
- facilitating adaptive management and learning.

These concepts/principles can be translated to the waste management industry, and specifically food and other UOW, as shown in Table 3.1

Table 3.1– Translation of IRP concepts and principles from water to waste/UOW

Water	Waste/UOW
Service provision	
IRP helps utility planners consider the 'services' provided (e.g. clean clothes) not merely the commodity itself (e.g. water). Defining essential services/utility systems around service needs allows utility planners to go beyond considering only hard technical systems/LTS that they are used to planning and managing and look at more efficient or alternative ways of providing the services required. This includes the basic principle that a kL of water saved or provided through alternate means, such as recycling, is equivalent to a kL supplied through an LTS such as a dam or desalination plant.	For waste, this can easily be translated to avoidance and minimising the tons of waste needing to be collected and treated to improve key public health service objectives (e.g. clean streets, reduction in vermin, minimisation of transmissible diseases) or minimise the amount of waste being collected and disposed to landfill (e.g. reducing service costs and potential environmental impacts). The concepts of nega-gallons or litres of water (providing the same service with less not more water), nega-kilowatts of electricity and nega-tons of waste originally stemming from authors such as Fuller (1969; 2008) and Lovins (1979), refer to Luke (2010).
Detailed disaggregation	
IRP generally involves disaggregating demand in a specific context into its component parts, typically sectors (e.g. residential, commercial), sub-sectors (e.g. houses, apartments) and where possible end-uses (e.g. toilets and clothes washers) that are affected by socio-technical factors (see below). Understanding current demand in such detail allows analysis of the existing efficiency and conservation potential within each component of demand as well as a way to think through alternative ways of providing those services. This includes different qualities of water from potable drinking water to toilet flushing and the concept of '*water quality cascade'* where the output from one end-use can feed into another (e.g. shower water used for garden watering) and potential waterless alternatives (e.g. compost toilets). This further reduces water supply needs. Such disaggregation forces planners to look at the whole systems and individual socio-technical components simultaneously (i.e. top-down and bottom-up analysis).	In waste, disaggregation into broad sectors and sub-sectors as well as different types of materials (e.g. glass and cardboard) is conceptually similar and generally practiced. However, there appears to be less application of disaggregation within UOW where the concept could be used to build up a more holistic picture of the types and quantities of UOW generated in any given region. This lack of application of both the detailed and holistic picture often compounded by the lack of detailed data collected on different streams of UOW. With a more detailed disaggregated picture, the scale of efficiency/avoidance and cascading potential could be used to begin to assess efficiency/avoidance and alternative services potential and design specific options based on that information. It could also help assess circular economy potential. For example, extraction of specific valuable chemicals followed by biogas energy extraction before final nutrient recovery as opposed to the current tendency (in Australia) to collect food waste and garden organics merely for composting purposes, thereby missing higher order circular economy and cascading potential.

Water	Waste/UOW
Detailed demand forecasting	
Forecasting in IRP builds on the concept of disaggregation and the need to understand disaggregated historical and current demand, as well as the factors that affect that demand. This to assist in better forecasting and ultimately the design of potential future options by sector, sub-sector and end-use where possible.	For waste, the concepts of disaggregating waste generation, understanding the factors that might affect waste generation and how these might be used to forecast future generation under different scenarios can be similarly applied (e.g. a gradual reduction in the proportion of SUDs with outdoor gardens generating garden organics over time versus an increase in lower occupancy MUDs with little or no garden organics). In forecasts observed, while some sectoral forecasting is conducted across waste flows there is often little if any disaggregation of food and other UOW or consideration of sub-sectors or end-use/micro-component analysis within those sectors (e.g. SUDs, MUDs, cafes, hospitals).
Considering a broad spectrum of demand- and supply-side options to satisfy service needs	
IRP aims to help satisfy service needs from soft-path, demand-side efficiency/avoidance and alternative sources through to hard-path, supply-side options. Demand-side options including a mixture of technical (e.g. efficient showers) and behavioural (e.g. shorter showers) measures tailored to the specific context being considered supported by various instruments (e.g. regulation, education and economic incentives). IRP options development in water often entails the consideration of dozens of demand-side options that are then compared against supply-side options during strategy development (Turner et al., 2010a).	Similarly in UOW, avoidance can play a key part in the portfolio of options available for consideration, from behavioural meal plans that minimise people making waste in the first place to technological equipment such as home composters that minimise materials needing to be collected, transported and treated at centralised locations. These are considered alongside on-site dehydrators in shopping precincts through to AD at wastewater treatment plants using macerated food waste trucked from large food manufacturers. Such solutions can be supported by regulatory, educational and/or economic instruments. However, in waste management, organics is often considered as a single or narrow suite of options and, if broken down, often merely considered as collection methods for industry scale composting or treatment. There are currently very limited examples of a broad suite of potential demand-side options considered in analysis in the same way as those considered in the water and energy sectors.
Comparison of options using a common metric, boundary and assumptions	
IRP requires the use of a common metric, system boundary and assumptions to enable fair comparison between demand- and supply-side options once developed. In simplistic terms, within IRP a kL or kwh saved is equivalent to a kL or kwh supplied. Analyses of options include consistent analysis of costs	In waste, the concept of nega-tons was first documented by Fuller (1969; 2008). Hence, this concept is not new but rarely exercised to its full potential as avoidance and smaller-scale treatment. It is rarely considered in terms of equivalence against LTS or in any great detail in terms of the vast and growing array of potential options at various scales

Water	Waste/UOW
and where possible avoided costs and other benefits (i.e. monetised and non-monetised externalities) such as associated energy use reduction in water (e.g. reduced hot water use via water-efficient showerheads). Comparison often involves the consideration of a suite of potential options and implementation of a mix of efficiency, alternative source and supply-side options, creating a 'portfolio' approach implemented over time rather than relying on a single LTS '*silver bullet*'.	available, despite the water and energy essential services industries demonstrating such potential. There are now a growing number of examples of food waste benefits being considered in the literature, both monetised and non-monetised and scoring against multiple objectives. But again often limited in terms of the number of options considered.
A participatory process	
IRP recognises that services are provided to consumers and communities and thus planning should involve these groups as key stakeholders in identifying the service needs, objectives and potential solutions.	Participatory processes are already demonstrated in the waste industry. However, with the growing number of food and other UOW stakeholders managing organics at different scales, there is a need to find ways to meaningfully broaden stakeholder representation and engagement instead of forcing a predetermined one size fits all/silver bullet solution upon them.
Adaptive management	
IRP recognises there is a level of irresolvable uncertainty, which is innate within complex systems dynamics. As such, it emphasises the need for iteration and learning, including a cyclical process of planning, implementation, evaluation and revision to manage essential/utility service systems over time and often incorporate new data and information as it becomes available from pilots and evaluations.	In waste, this concept is directly transferable. However, with an historical tendency for jurisdictions to opt for long-term LTS, such as landfill and incineration together with private industry tying customers into long-term contracts to guarantee feedstock and income to pay for new private infrastructure investment there is little incentive for adaptive management. Although, in the current environment policies are shifting (i.e. circular economy and energy), and learnings from the recent mixed use organic output experience in NSW (see Box 1), more emphasis is likely needed on iteration and shorter and tighter cycles of planning and evaluation. This provides scope for the collection of much-needed data, testing and evaluation of innovative options of various scales for broader roll out instead of opting for blanket replacement LTS resulting in potential over capitalisation and suboptimal sustainability outcomes.

Key differences between the water and waste/UOW sectors that may make the use of IRP more challenging, using Australia for context, include:

- While waste is considered an essential service in NSW, similar to water and energy, there has been inconsistency across Australian jurisdictions (Norton Rose Fulbright, 2020), potentially due to waste's temporal urgency when disrupted (i.e. water and energy services have key performance indicators measured in terms of hours of disruption, which is not the case for waste) and perhaps a perceived lower level of professionalism when compared to other essential services (Davis, 2015; 2016).
- Core infrastructure in water is typically owned by a local government or state-owned corporation with investment in that infrastructure paid through regulated water rates. Infrastructure ownership in waste varies. In regional areas, most councils own their own assets as a single entity, but in Sydney, for example, major waste infrastructure was sold off in 2010 to the private sector (LGNSW, 2017). Hence, ownership is dispersed and managed through a complex supply chain by multiple stakeholders for multiple waste streams from large international private companies to local government and now also smaller service providers trying to break into new markets. Hence, new infrastructure is typically developed in an open market, with private companies responding to financial opportunities and government grants rather than prioritised need.
- Water services are provided through 'user pays' principles based on a 'service' connection plus per kL usage fee based on block tariffs. Metering and service charges have been in place in Australia since around the 1980s (White, 1998), with the national requirement for metering of water consumption since the mid 1990s (Koech et al., 2018). The vast majority of waste however is not measured at source. Hence, in the residential sector, waste charges are part of council rates bills (in fact often the largest component) and based on a weekly/biweekly collection service, irrespective of customers usage of that service. For non-residential customers, waste is typically charged per bin lift (according to bin size) but typically not weighed unless over an allowable weight, triggering additional fees.
- While, as identified in Table 3.1, water is typically provided as potable drinking water, there are various qualities used depending on the end-use (i.e. water quality cascade) that can be used and/or recycled depending on that usage. In waste, this is similar but perhaps more challenging due to the multiple streams in the urban environment with differing levels of quality and contamination managed through multiple channels.

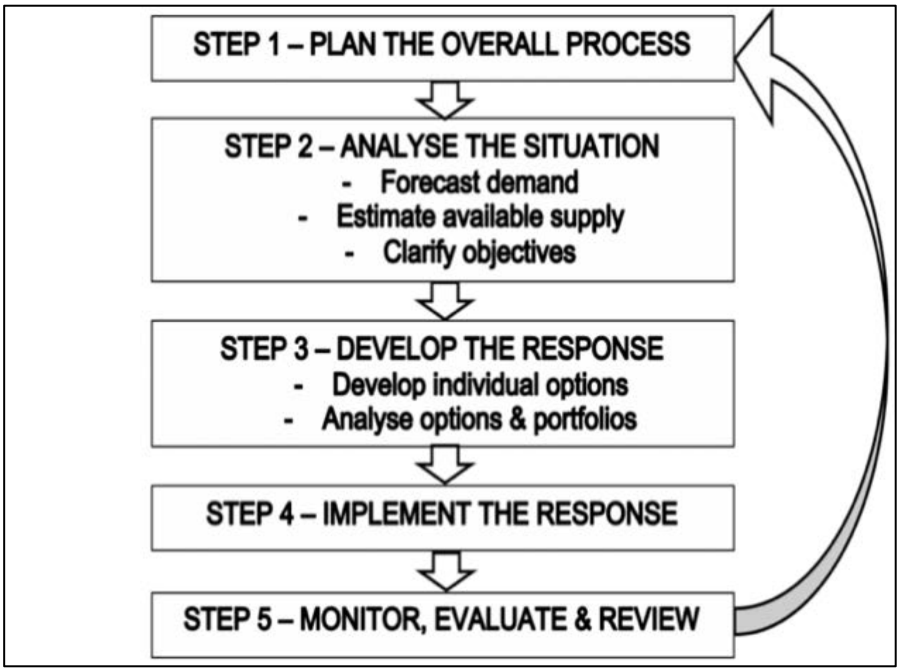
These differences between water and waste/UOW make the use of IRP more challenging. However, due to the complexity of waste generation and management, using the IRP approach and method of inquiry would appear even more useful to unveil that complexity and help make decisions on managing UOW through a diverse set of context-specific options.

3.2.3 KEY STEPS

An (a) simplified and (b) full version of the five-step IRP process, developed and used in Australia for planning and decision-making in the water industry, is shown in Figure 3.1 (Turner et al., 2010a). This approach has been used extensively:

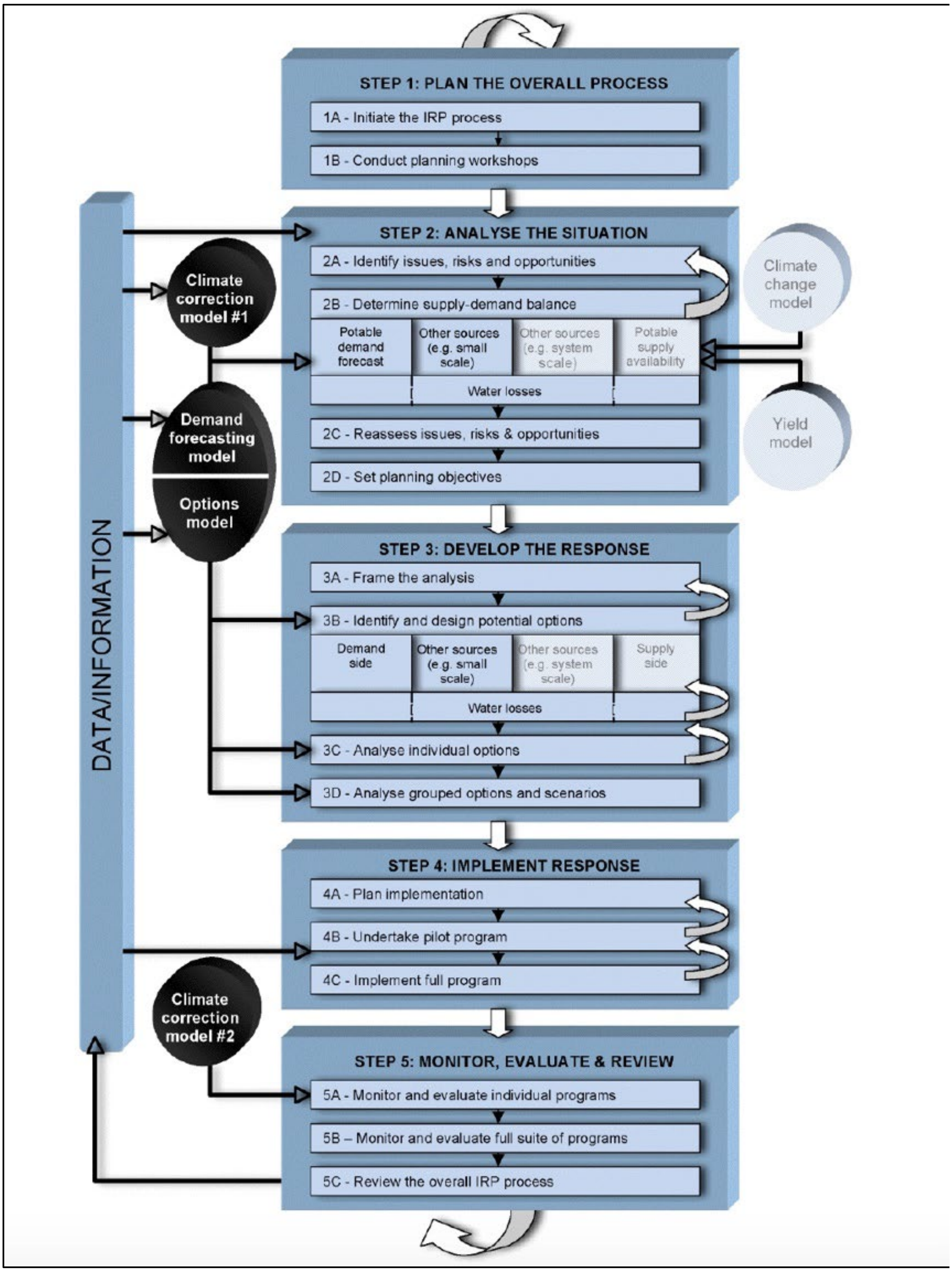
- for small towns, large cities and regions
- by small council teams as well as for multi-agency regional planning groups
- within Australia where data has improved, to developing and emerging economies where data is often poor
- to aid learning and knowledge transfer and as part of participatory planning processes
- at a conceptual level to aid systems understanding through to a more detailed level when data is available and can be modelled.

Figure 3.1 – IRP framework
(a) Summarised IRP framework



(Adapted from Fane et al., 2011)

(b) Full IRP framework



(Source: Turner et al., 2010a)

Key steps used in a water IRP planning cycle include (Turner et al. 2010a):

- **Step 1 – plan the overall process**: Identify core planning team, stakeholders and resources available and familiarise stakeholders with the IRP process and overall context of the region under investigation. Consider primary objectives of planning exercise and the boundary of analysis.
- **Step 2 – analyse the situation** (**or context**): Conduct situation/context analysis examining the disaggregated supply–demand balance (historical, current and projected demand by sector, sub-sectors and end-uses where possible). Consider factors affecting demand (e.g. demographics, underlying efficiency, economic growth) and possible future scenarios (e.g. industrial decline, tourism growth, policy change). In parallel, assess current and projected system yield, including the potential impact of climate change and the supply–demand balance. Based on collated and analysed, context-specific information to clarify planning objectives.
- **Step 3 – develop the response**: Using a consistent boundary of analysis (and timelines and assumptions) develop a broad suite of potential interventions or options, both soft-path demand-side and hard-path supply-side. Such options are designed based on the context details elucidated in Step 2. Analyse savings and supply potential for each option, whole-of-society costs and, where possible benefits and assess broader factors (e.g. sustainability, feasibility, risk). Conduct stakeholder deliberation on the suite of options available to determine a preferred portfolio of options to implement based on identified objectives and criteria.
- **Step 4 – implement the response:** Consider team roles and responsibilities, cost-sharing arrangements, timing, budgets, and communication and education, and pilot and evaluate programs prior to full implementation.
- **Step 5 – monitor, evaluate and review**: IRP should be iterative, allowing for ongoing learning. Monitor and evaluate savings achieved, participation, costs, progress against planning objectives and the IRP process overall. Ensure knowledge, data and experiences are used in subsequent iterations of the process to enable improvements.

A key point here is that the concepts behind IRP and the associated steps guide the inquiry, whether coming to the process for the first time or after decades of use (i.e. there are a spectrum of users). It helps those involved to use what information and data they have available to them and through a process of iteration, learning and review, specific data and information gaps can be filled gradually to reveal deeper insights where possible (i.e. clarity around why and how to collect data as well as making the most of the data at hand). This iterative process has been used in countless water examples in Australia (Turner et al., 2010a; 2016) and overseas in areas with little data and information (Turner et al., 2005; White et al., 2011; White & Turner, 2022). The iteration occurs both within and between planning cycles.

Also key is that IRP helps understand the detail of the specific context being investigated, such as how a resource is being used, and based on that information determines through a broad spectrum of solutions how that service can be provided with least draw on resources, at the lowest cost to society and with the greatest benefits. This strong linkage between understanding the system in question in depth and finding solutions that respond to that specific context through a broad suite of demand- and supply-side solutions is surprisingly mute or absent from other planning and decision-making frameworks and a key strength of IRP compared to other approaches.

3.3 THE LINKAGE BETWEEN IRP AND SYSTEMS THINKING

So IRP can assist utility planners to go beyond historical practices of merely considering the hard infrastructure system alone and the use of basic forecasting techniques and reliance on a handful of LTS solutions towards more complex socio-technical system concepts. Hence at its core, IRP aims to help planners, in a practical way, to consider multiple types of systems within their jurisdiction, beyond just the hard systems they are used to, and through observing and analysing those more complex socio-technical systems find both hard- and soft-path solutions to a planning problem that can fulfil multiple objectives and provide multiple benefits.

When IRP emerged in the 1970s, it did so in parallel to systems thinking theory and concept development. Hence, although IRP is inherently a systems thinking approach, it does not necessarily use systems thinking terminology but does apply many of its key tenets (Turner & Fane 2023). After a brief overview of systems thinking, the linkage between IRP and systems thinking is further examined below and brought to the fore. By observing these linkages, the theoretical underpinnings of the practical IRP approach can be seen, actively strengthened and gaps potentially filled.

3.3.1 SYSTEMS THINKING

Systems thinking has a long and diverse history. It has numerous approaches and methods of inquiry, an array of tools to assist in that inquiry and can be considered from multiple perspectives according to the area of interest of the scholar or practitioner using the approach. It is now used for a broad spectrum of theoretical and practical applications (Amissah et al., 2020).

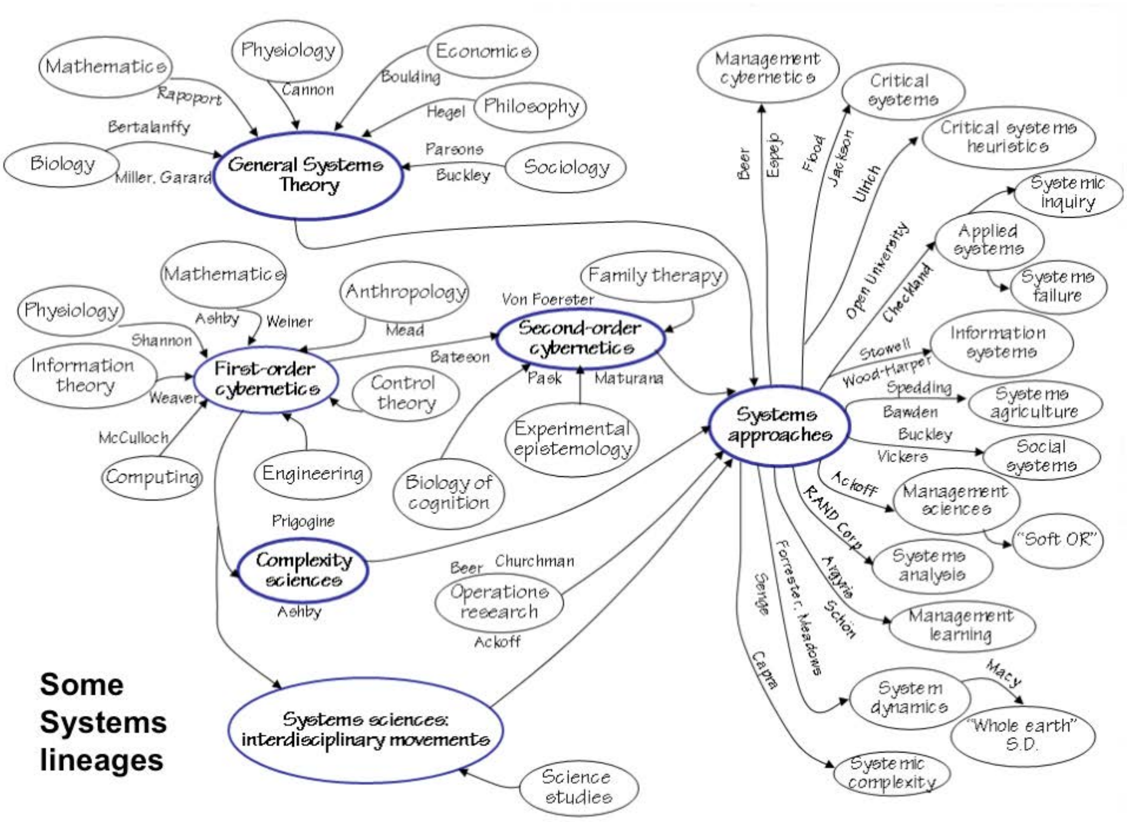
In essence it is an approach to reasoning and treatment, mainly of real-world problems, based on the fundamental concept of systems (Amissah et al., 2020). According to Meadows (2008 p11), a 'system' in simplistic terms is "an interconnected set of elements that is coherently organized in a way that achieves something" and thus must be comprised of elements, interconnections and purpose or function and "as a whole cannot be divided into independent parts without loss of its essential properties or functions" (Ackoff, 1999, p8). Systems thinking basically seeks to understand the relationships between elements and their impact on system outcomes, whether intended or unintended, and how that system sits within the broader context of its environment (Amissah et al., 2020).

Figure 3.2 helps to illustrate one conceptualisation of the lineage of systems, related approaches and some of the key authors. These from:

- the Austrian biologist Bertalanffy, instrumental in developing General Systems Theory in the 1940s to help explain natural systems but whose principles could be translated to other fields (Bertalanffy, 1969)
- operations research, a more analytical approach to systems used for hard engineering problems and decision-making that emerged in parallel during the challenges of World War II with a focus on optimisation (Jackson, 2009), through to
- more soft systems inquiry approaches championed by Checkland and his interpretation that systems are observer defined constructs rather than real-world entities (Checkland, 1978).

Thus, helping to illustrate the diversity of systems-based approaches.

Figure 3.2 - Systems thinking lineages



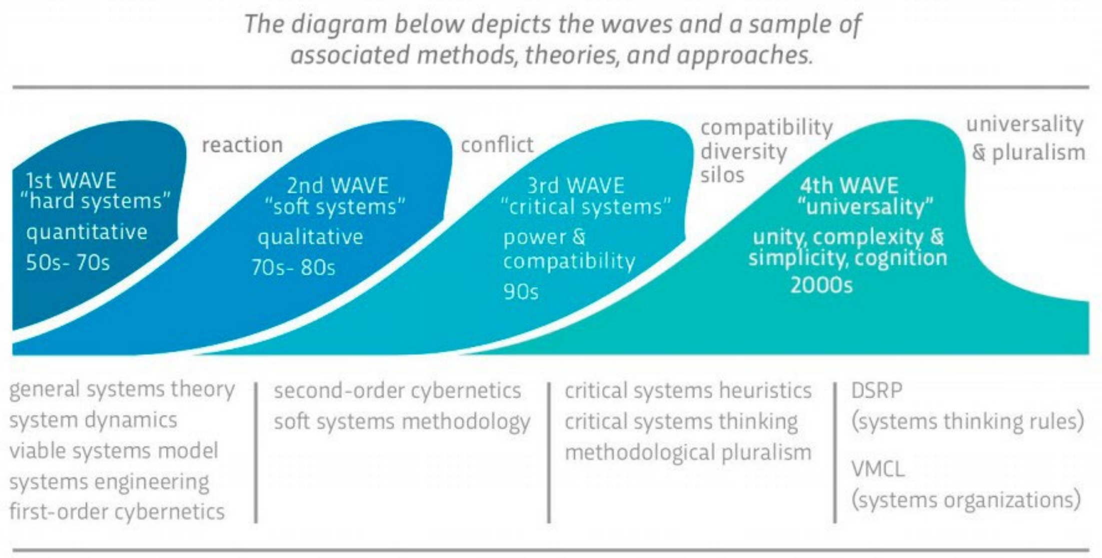
(Source: Ison, 2008)

Another way of looking at system thinking is to consider the waves of the development of theories and approaches (Midgley, 2000; Midgley & Rajagopalan, 2021) as illustrated in Figure 3.3:

- The first wave centred around hard systems, goal-orientated analysis and achieving efficiency and optimisation.
- The second wave was somewhat of a backlash against hard systems centric approaches and had more of a focus on soft systems approaches, thinking of systems as a construct as opposed to a real entity and bringing to the fore learning-orientated appreciative inquiry to help achieve effective outcomes.
- The third wave tried to appreciate both previous waves and acknowledge theoretical and methodological pluralism as well as dealing with power, inclusiveness and ethical outcomes.
- The fourth wave, emerging in the last decade or so, focuses more on appreciating complexity but also ways of thinking through (i) the use of systems thinking skills (often summarised as distinctions, systems, relationships and perspectives (DSRP) see Box 3 below) and (ii) questioning the Western scientific approach of privileging

rational analysis and truth-orientated inquiry over other experiential, presentational and practical ways of knowing demonstrated in many other cultures for centuries.

Figure 3.3 - Systems waves concept



(Source: Amissah et al., 2020)

Box 3 - DSRP

According to Cabrera (2006) and Midgley and Rajagopalan (2021) systems thinking involves:

people making value/boundary judgements or *distinctions* (D) within and between *systems* (S) where the parts have a *relationship* (R) with one another and can each be viewed from a *perspective* (P) - DSRP

As can be appreciated from the long history of systems thinking and broad array of theorists and practitioners, there is also an array of concepts or tenets that are still growing as the area of interest broadens and deepens. Key concepts were identified by a diverse spectrum of theorists and practitioners in a recent 2019 colloquium on systems thinking (Amissah et al. 2020) and include considering (Armson, 2011):

- systems not as independent random items but **components** that are **interconnected** and provide a **function**, purpose or **service** as well as the potential for **emergent functionality**
- systems as part of a **hierarchy of systems** within systems (i.e. components, subsystems and systems) each with their closed or open system **boundaries** that interact or have the potential to interact with other systems and their **environment** to varying extents (see Figure 1.8), which the system/s are unlikely to have control

- the component parts of the system through **analytical disaggregation** while simultaneously seeing the **whole system** along with the **relationships** and **interconnections** through **synthesis**
- **dynamic** systems and subsystems that have varying levels of **complexity**, interconnectedness and predictability, sometimes with emergent properties and/or potential irresolvable **uncertainty**
- interventions that have both **positive and negative feedback loops** that can lead to virtuous or vicious circles, where positive feedback loops tend to amplify or enhance changes and make a system more unstable, while negative feedback loops tend to bring it back into equilibrium.

Looking at the soft systems perspective more closely, Table 3.2 helps to further differentiate between hard and soft systems thinking. Associated soft systems methods, also termed '*soft operations research*' or '*soft OR*' methods, are often collectively termed under the broad umbrella of '*problem structuring methods'* or '*PSM*'. This term was introduced by Rosenhead (1989) to describe methods that focus on structuring of a problem situation rather than merely solving it (Mingers & Rosenhead, 2001). This originally aimed to help overcome the perceived failure of traditional hard operations research optimisation methods that addressed ill-structured problems (Rosenhead, 2006), or were 'answering the wrong question'. Such problem structuring methods are extensively covered in MCDA literature (Belton & Stewart, 2002; 2005; 2010; Marttunen et al., 2017). Effective problem structuring is critically important as the subsequent analysis is strongly affected by such framing and the associated complex decision-making requires clarity on the different perspectives, values and preferences of those responsible for and impacted by those decisions (Belton & Stewart, 2005; Marttunen et al., 2017).

Table 3.2 – Key differences between hard and soft systems thinking

Hard systems thinking	Soft systems thinking
• Orientated to goal seeking • Assumes the world contains 'systems' that can be engineered • Assumes systems models to be models of (part of) the world • Uses the language of 'problems' and 'solutions' • Philosophically positivistic • Sociologically functionalistic • Systemicity lies in the world	• Orientated to learning • Assumes the world is problematical but can be explored using systems models of concepts of purposeful activity to define 'action to improve' • Assumes systems models to be 'devices': intellectual constructs to help debate • Uses the language of 'issues' and 'accommodations' • Philosophically phenomenological • Sociologically interpretive • Systemicity lies in the process of inquiry into the world

(Adapted from Checkland & Howell, 2004)

Numerous methods have been developed under soft system/soft operations research/problem structuring methods, each with their own swathe of supporting literature. As identified by Leleur (2012) and Marttunen et al. (2017) some typical methods used include:

- Brainstorming (Osborn, 1953; Besant, 2016)
- Stakeholder Analysis (Grimble & Wellard, 1997)
- Mind mapping techniques (Montibeller et al., 2008; Schaffernicht, 2010)
- Drivers, Pressures, States, Impacts, Responses (DPSIR) (OECD, 1993)
- Strengths, Weaknesses, Opportunities, Threats (SWOT) (Kotler, 1988)
- Scenario Planning (Schoemaker, 1995)
- Strategic Alternatives Surfacing and Testing (SAST) (Mitroff & Emshoff, 1979)
- Strategic Options Development Analysis (SODA) (Ackermann & Eden, 2010)
- Soft Systems Methodology (SSM) (Checkland & Scholes, 1990)
- Critical systems heuristics (CSH) (Ulrich, 1983; Jackson, 2000)

While Rosenhead (1989) may have initially conceived some of these methods as ways of framing the initial problem structure, Marttunen et al. (2017) illustrate that they can be used throughout decision-making processes such as MCDA, as illustrated in Table 3.3. Each method provides varying levels of support. For example, stakeholder analysis may not provide significant support in the latter stages of decision-making but is key in the early stages, as indicated in Box 4.

Table 3.3 - Level of support provided by various PSMs to different aspects of decision-making processes

	Stake-holder Analysis	Cogni-tive, Group Maps	DPSIR	SWOT*	Scenario Planning*	SAST*	SODA*	SSM**	SCA*
Defining the frame	Small	Strong	Moderate	Small	Small	Moderate	Strong	Strong	Small
Identifying stakeholders	Strong	Small	No	No	No	No	No	Moderate	No
Identifying criteria	Small	Strong	Strong	Strong	Small	Moderate	Strong	Small	Strong
Defining attributes	No	Small	Small	No	No	No	No	Small	No
Developing alternatives	No	Moderate	Small	Moderate	Moderate	Moderate	Strong	Moderate	Strong
Identifying uncertainties	No	No	No	Small	Strong	Strong	No	No	Strong

No support; Small support; Moderate support; Strong support

* Stakeholder analysis is typically part of the method(ology)
** SSM includes CATWOE, root definitions, rich picture, 3Es (Efficacy, Efficiency, Effectiveness)

(Source: Marttunen et al., 2017. Republished with permission of Elsevier via CCC)

Box 4 – Stakeholder analysis

Stakeholder analysis, "a holistic approach or procedure for gaining an understanding of a system, and assessing the impact of changes to that system, by means of identifying the key actors or stakeholders and assessing their respective interests in the system" (Grimble & Wellard, 1997: p175) is commonly used in soft systems/soft operations research/problem structuring methods (Leleur, 2012). Due to the importance of stakeholders in IRP (International Rivers, 2013; AMWA, 2017; Tellus, 2000; Turner et al., 2010a) it is often implicitly conducted to help determine who should be involved in an IRP planning and decision-making exercise (at what points and how) and who might be needed to assist in implementing the diverse demand- and supply-side solutions developed (i.e. IRP Step 4). Being implicit, it is not however necessarily practiced with much rigour or structure in IRP. This is similarly found in MCDA, which equally values stakeholder involvement (Marttunen et al., 2017).

Stakeholder analysis methods and approaches have been developed within different fields for different purposes but often centre around identifying and categorising stakeholders and investigating relationships between stakeholders when dealing with resource management (Reed et al. 2009). While stakeholder analysis may have been criticised in the past for a potential lack of analytical quality (Hermans & Thissen, 2009), various typologies (Reed et al., 2009) and gaps are being filled for infrastructure and resource management (Lienert et al., 2013; Lyon et al., 2020). Even using its simplest form it helps provide recognised structured methods to help consider stakeholders for planning and decision-making approaches, such as IRP and MCDA.

3.3.2 LINKAGE BETWEEN IRP AND SYSTEMS THINKING WAVES AND KEY CONCEPTS/TENETS

In terms of linkage with systems thinking, IRP portrays both first and second wave systems thinking according to Midgley's (2000; 2006) interpretation but also Ulrich's (1988) operational and strategic systems practice nomenclature. For example, looking at the first wave or operational approach, IRP breaks demand down into components and types of use (i.e. sectors, sub-sectors, end-uses and function or service) through numerical modelling and using a goal-orientated approach to help consider how to improve efficiency for real or hard infrastructure systems. However, it also draws on more abstract soft systems concepts (i.e. socio-technically influenced end-uses and behaviours leading to services that are a function of and directly influence the management of a hard infrastructure system).

As a second wave or strategic approach, IRP brings into focus the human elements both in terms of the detailed interaction with the service of the end-use technologies and behaviour but also consideration of the broader context of the system including communities, institutions and policy interventions to achieve preferred outcomes. These preferred outcomes are not necessarily known at the start of the planning exercise, but can emerge. This is especially when considering a diverse spectrum of options developed and considered by a broad range of stakeholders in a deliberative way. Such deliberative processes, when planned well, often leading to multiple benefits that would not have been evident when using traditional hard system planning approaches alone.

IRP also therefore portrays some third wave characteristics in terms of embracing a 'pluralist' approach (i.e. hard and soft system perspectives) and puts a focus on cyclical implementation based on monitoring, evaluation, review and revision. Ideally giving a learning-orientated approach for interventions adopted. However, while there are examples in water IRP of the use of '*soft systems/soft operations research/problem structuring methods'* used at various points within the process (White et al., 2008), this is perhaps an area of IRP that could be further explored and/or strengthened through stronger linkage with systems thinking. It also potentially lacks other characteristics of third wave systems thinking, such as 'ensuring inclusiveness' and dealing with 'power'. Both of these are particularly important in essential services provision and even more so in waste management, where private investment and associated decision-makers can dominate the industry (especially in Australia) and are likely less motivated by social and environmental issues. This power struggle is even evident in water IRP, as illustrated in Box 5, despite its decades-long application and where the water is typically planned and managed by state-owned corporations or local councils. Hence, this is also an area where IRP could be strengthened (as could many other planning and decision-making approaches). Neither, as identified in fourth wave systems thinking, does IRP specifically teach practitioners to be 'systems thinkers' as advocated in the fourth wave systems thinking, although through IRP practice this often becomes intuitive to some extent.

Box 5 – 'Drought or no drought'; Power versus good decision-making

There are many examples of power taking over good decision-making, including those based on IRP. Several took place during the Australian Millennium Drought, such as the AUD 2 billion desalination plant in Sydney (Giurco et al., 2014; Turner et al., 2016). In 2006, the decision to build a desalination plant was put on hold when the NSW Government adopted the Metropolitan Water Plan review recommendations, including a portfolio of demand- and supply-side options and an innovative 'readiness' option (White et al., 2006). While formally adopted by multiple stakeholders involved, and based on IRP principles, it was subsequently overtaken by political imperatives in 2007 when the dam levels reached 34%. Due to concerns that the dam levels could approach trigger levels of 30% during the 'caretaker period' (a short period between when an election is called and the date of the election), a decision was made to pre-empt the trigger levels and proceed with the desalination plant. Even though it began to rain shortly afterwards and the dam began to fill, the desalination contract was signed when the dam levels were at 55%. By 2012, when the dam had overflowed and construction and subsequent testing was completed, the desalination plant was shut down as it was not required. This raised major concerns about the decision-making process and associated political intervention (Australian Government Productivity Commission [AG PC], 2011). The desalination plant was eventually used in 2019 when dam trigger levels reached 60% but over a decade after the decision was made to build it (Sydney Desalination Plant [SDP], n.d.).

Key systems thinking concepts or tenets shared with the IRP approach include:

- Providing a **function or service** – Not seeing utility planning in terms of the hard infrastructure alone but as a socio-technical system defined around service provision.
- **Multi-functional/objective** – Considering such components not as independent items but a system of interconnected elements that, as well as providing functions or services, can have **emergent functionality** (e.g. for water, green gardens providing cooling properties in arid climates; or for food and other UOW, home composting providing improved soil health and nutrient access for plants, improved plant yields and contented gardeners) and thus have the potential to fulfil multiple functions or services and objectives that may not be initially evident or foreseen.
- **Stakeholders** – The importance of involving stakeholders in the planning and decision-making process to appreciate multiple perspectives, values and preferences.
- **Analytical disaggregation** and **synthesis** – Breaking demand down into components (i.e. end-uses or micro-components, subsystems and associated services) for analysis

and as a tool for thinking through service needs while also considering the system/s as a whole (e.g. efficiency, alternative sources, supply-side LTS) including interconnections.

- **Hierarchy of interacting systems** – A hierarchy of systems within systems (i.e. components, subsystems and systems) each with their closed or open system **boundaries** that interact or have the potential to interact with other systems and their environment to varying extents (i.e. waste-wastewater-energy-agriculture) with both potential positive and negative impacts.
- **Uncertainty** – Dynamic systems and subsystems that have varying levels of complexity, interconnectedness and predictability. Sometimes with potential for irresolvable uncertainty (i.e. in water uncertainty around climate change affecting the available yield of supply-side dams leading to the need for adaptive management and scenario planning for decision-makers to try to deal with a range of potential futures).

For the above key concepts or tenets, while IRP demonstrates each, explicitly linking with systems thinking helps expand and deepen our theoretical understanding of each and how they can be more effectively incorporated into IRP practice, and where necessary, strengthened. These key concepts or tenets and linkages are discussed further in Section 3.5.

3.4 SUSTAINABILITY TRANSITIONS

As identified in Section 2.5.4, there are opportunities to augment and strengthen the IRP concepts and framework with other approaches. In considering UOW I have been particularly drawn to sustainability transitions due to its:

- foundational alignment with many systems thinking tenets (Geels, 2004; Markard, 2017)
- broad observation of the historical and current socio-technical situation/context and drivers
- specific focus on the emergence of innovation
- futures-orientated vision and pathways approach on transition and transformative change.

Here I outline some of the key literature and concepts of sustainability transitions before considering which concepts have the potential to augment IRP and help fill some of the gaps and opportunities identified in Section 2.5, Table 2.1. A summary discussion is then provided in Section 3.5.

3.4.1 OVERVIEW

Transition, used in many disciplines, is typically understood as the nonlinear shift from one dynamic equilibrium to another. Sustainability transitions emerged at the end of the 1990s (Rotmans et al., 2001; Grin et al., 2010) as an inter- and trans-disciplinary research field in response to the growing need to deal with the myriad of challenges we now face as a large and rapidly growing society, such as, population growth, resource depletion and scarcity, increased waste and the impacts of climate change. While sustainability transitions can be explored and described in many ways, there are a number of common concepts, areas of interest and focus. The core aim of sustainability transitions research is to better understand transitions, anticipate and adapt to undesirable ones and explore opportunities to advance and accelerate desirable ones by focusing on fundamental systemic changes, centring around societal regimes, that help move towards large-scale societal sustainable transformation (Loorbach et al., 2017).

As with IRP's initial focus (see Section 3.2.1), a key transition observed through sustainability transitions has been the energy sector and the struggle of moving from fossil fuels towards renewable energy systems (Loorbach et al., 2017). However, many other sectors have historically experienced similar major transitions, such as, the development of water and wastewater pipe networks in developed countries to help solve sanitary health issues, as well as other diverse industries such as the automobile and music industries, each reflected upon using techniques developed in sustainability transitions (Geels, 2005a; 2005b; 2006; 2007). While major transitions have already occurred, they are likely to occur again (Verbong & Loorbach, 2012; Sovacool, 2016), especially when considering the rapid technology advances of the fourth industrial revolution.

With waste being such a key contributor to resource use, waste generation and climate change, and set to increase due to population rise both per person and overall (Hoornweg et al., 2015), it is a core issue that requires transformation towards more resource focused sustainable practices. Due to the growing concerns associated with unsustainable consumption, there is growing discourse, much around the need to go beyond merely making consumption more efficient or decoupling it from energy and resource use. That is, to go much further to deeper levels of system change, '*deep transition*', and transformation in multiple key areas of consumption (i.e. transport, housing, energy use and food) to meet the scale of sustainability challenges now faced (O'Rourke & Lollo, 2015; Schot & Kanger, 2018).

Sustainability transitions has grown over the last two decades with collaborations such as the Sustainable Transitions Research Network (STRN)[10] and associated conferences, journals and research agenda (Kohler et al., 2019). Sustainability transitions is now used globally for a range of sectors and societal issues such as energy, water, resources, food and transport through to healthcare and education (Loorbach et al., 2017). The field also explores geographical issues from regions and cities to smaller communities (Wolfman, 2016; Wittmayer et al., 2015) and has seen a shift away from its original focus mainly on socio-technical systems to recognition of socio- ecological, economic, and political systems (Loorbach et al., 2017).

Urban essential services systems (i.e. water, wastewater, energy and waste), are termed socio-technical systems within sustainability transitions (similar to LTS terminology [Hughes, 1987]) and are comprised of networks of actors, institutions, material artefacts and knowledge (Geels, 2004; Markard, 2011; Weber, 2003). These established, large and typically complex socio-technical systems are intertwined with existing user practices, technologies, business models and organisational and institutional structures (Rip & Kemp, 1998). As such they are typically prone to '*lock-in*' due to both their established nature (Ahman & Nilsson, 2008; IEA, 2011; Safarzyńska & Van den Bergh, 2010; Unruh, 2000) and the often-substantial sunk investment in large-scale technology and networks (Geels, 2010), or LTS, that may last many decades. Due to these characteristics, such systems often undergo incremental change and a tendency to optimisation of existing systems rather than the radical change potentially required to deal with the sustainability challenges currently being faced (Dosi, 1982; Frantzeskaki & Loorbach, 2010; Markard & Truffer, 2006).

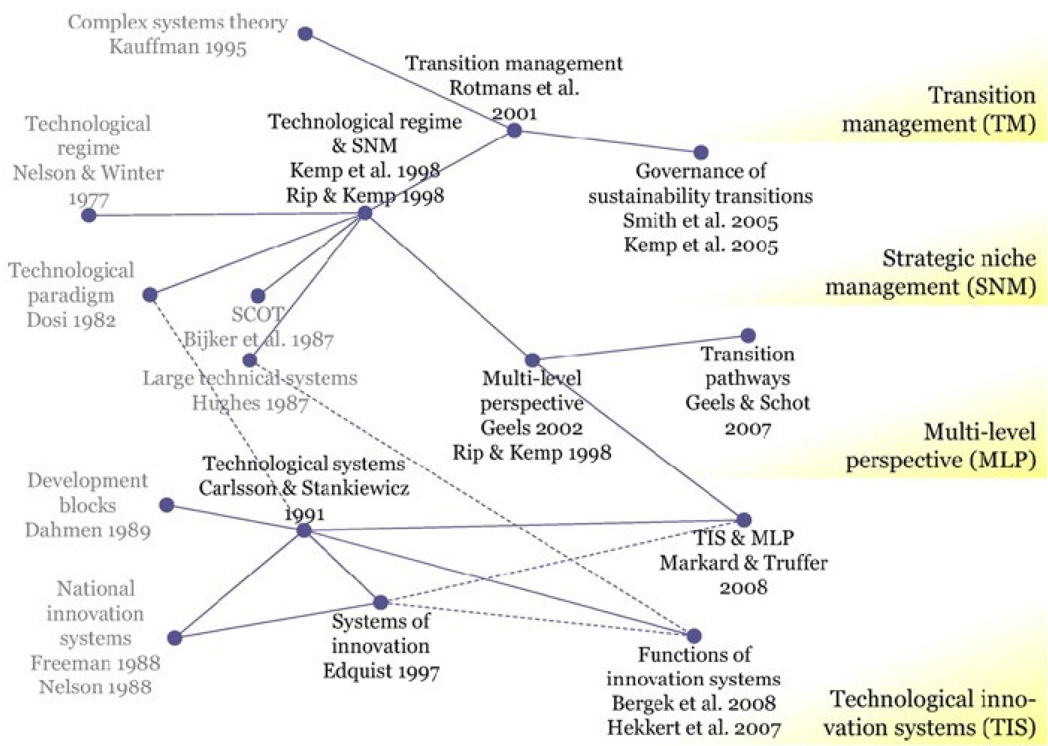
Socio-technical transitions involve fundamental and far-reaching multifaceted changes in technical, material, organisational, institutional, political, economic, and socio-cultural dimensions (Geels & Schot, 2010; Markard et al., 2012) that have occurred over several decades and result in new products, services, business models and organisations (Markard et al., 2012).

[10] https://transitionsnetwork.org (accessed 01/05/23)

To transition towards sustainability, through, for example, fundamental transformation towards more sustainable modes of production and consumption, many frameworks and perspectives have emerged under sustainability transitions studies (Loorbach et al., 2017). There are, however, four key frameworks, shown in Figure 3.4 along with the associated theory landscape. As outlined by Van de Bergh et al. (2011), Markard et al. (2012), and Loorbach et al. (2017), the four frameworks are:

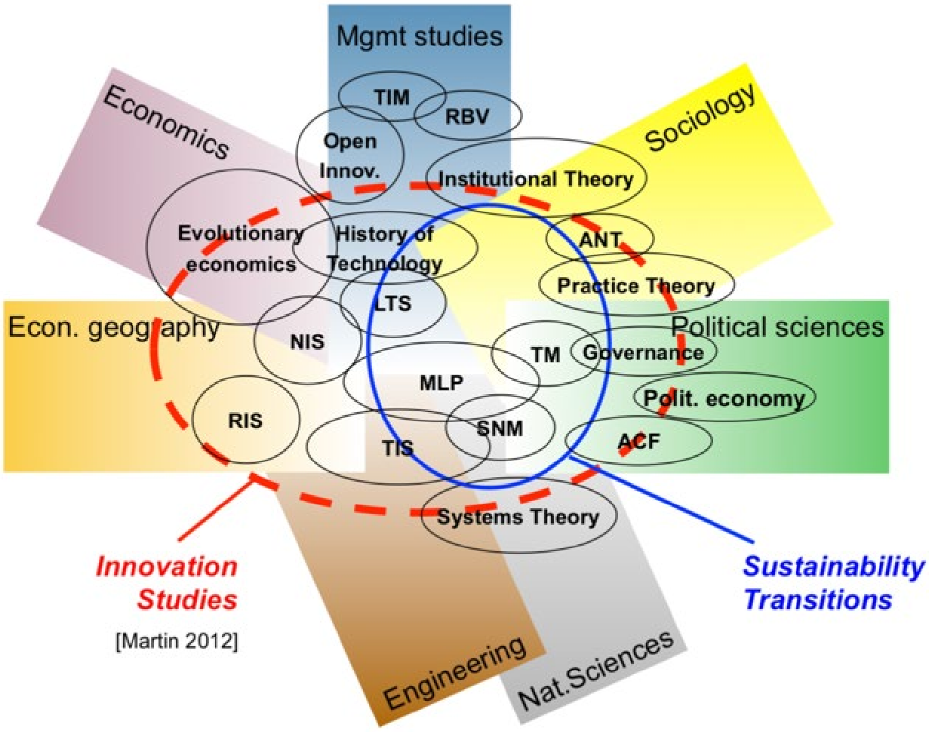
- **multi-level perspective (MLP)** (Rip & Kemp, 1998; Geels, 2002; Geels & Schot, 2007; Smith et al., 2010)
- **transition management (TM)** (Kern & Smith, 2008; Loorbach, 2010; Rotmans et al., 2001; Kemp et al., 2007; Rotmans et al., 2007)
- **strategic niche management (SNM)** (Kemp et al., 1998; Raven & Geels, 2010; Smith, 2007)
- **technological innovation systems (TIS)** (Bergek et al., 2008; Jacobsson & Johnson, 2000; Hekkert et al., 2007).

Figure 3.4 – Lineage & theory landscape of the four key frameworks considered central to sustainability transitions
(a) Lineage



(Source: Markard et al., 2012. Republished with permission of Elsevier via CCC)

(b) Theory landscape



(Source: Markard, 2017)

Each framework tends to approach transition from a slightly different perspective and use a variety of heuristics and tools, with MLP providing much of the core language commonly used by the other approaches. While the concepts in MLP are the main approaches, I consider transition management and strategic niche management here as well. This is due to transition management's proactive approach to managing the transition and overarching alignment with IRP as an adaptive management approach and strategic niche management's deeper consideration of innovative socio-technical systems and potential challenges to adoption, which are playing out in the real world of food and other UOW management.

3.4.2 MULTI-LEVEL PERSPECTIVE (MLP)

The MLP framework emerged predominantly from research by Rip and Kemp (1998) and was extended by Geels (2002) and much of his retrospective analysis (Loorbach, 2010) of historical socio-technical transitions (Geels, 2002; 2005a; 2005b; 2006; 2007), and many subsequent authors who have expanded and critiqued the approach (Genus & Coles, 2008; Geels 2011; Markard & Truffer, 2008). As identified by Geels and Schot (2007) and Sorrell (2018), MLP focuses on the concept of three interacting levels:

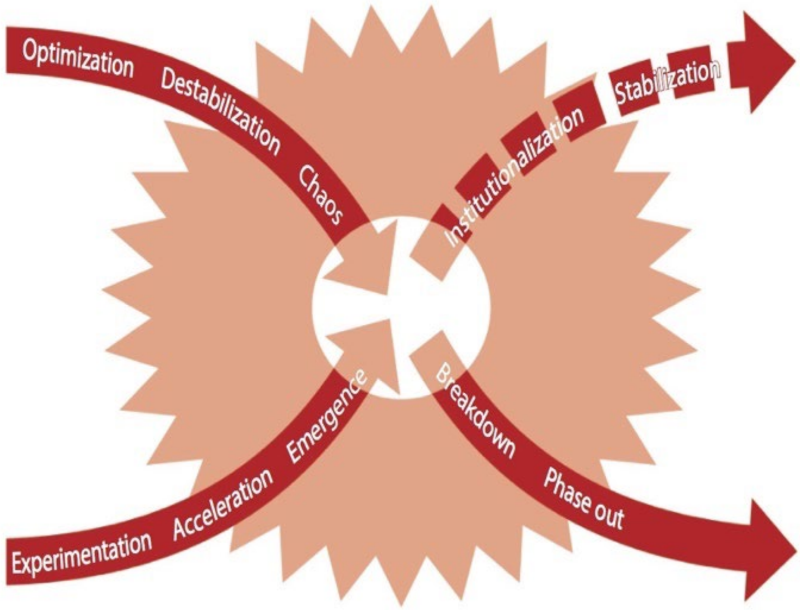
- **Landscapes (macro-level)** – An external environment largely beyond the control of the actors in the system (e.g. broader physical, political and economic environment), which affects the core socio-technical system (Geels, 2002; 2004), and influences that system through drivers that can vary from gradual trends or shifts (e.g. cultural preferences, demographics) to short-term shocks (e.g. economic recessions).

- **Regimes (meso-level)** – The incumbent socio-technical system made up of dominant technologies, infrastructure, industries, supply chains and organisations providing a societal function. Those in the regime are influenced by rules, shared meanings, routines and social norms (Geels, 2002; 2004) that create stability for the dominant socio-technical systems and resistance to change. Innovation within the existing system is typically incremental and liable to 'lock-in' due to sunk investments, economies of scale, vested interests, design standards, and entrenched social norms. Instability potentially resulting in those systems that cannot be resolved through incremental change.
- **Niche innovations (micro-level)** – Such emerging technologies develop on the fringe of incumbent systems. They are often initially relatively expensive, perform poorly compared to established technologies, lack appropriate infrastructure, user or regulatory acceptance and find it difficult to compete with the existing system (Geels, 2002; Schot & Geels, 2008). However, they can gain acceptance within particular geographical areas, markets, applications, or through targeted policy interventions. They are typically developed in more fragile, unstable social networks with competing technologies, designs and visions and often fail but can gain enough momentum to improve performance, reduce costs and achieve more widespread adoption resulting in acceptance by social groups and markets together with increased access to financial, political and other resources (Hoogma et al., 2002; Kemp et al., 1998). Under such conditions, they can 'breakthrough', challenging the existing regime.

Importantly, in MLP the landscape typically exerts pressure on an incumbent regime, and that it is the alignment of the landscape, regime and niche that help to destabilise the current regime creating a '*window of opportunity'* for emerging niche innovations to compete with, modify and potentially replace the incumbent regime (Geels, 2002; Geels & Schot, 2007), as depicted in Figure 1.7(b) in Section 1.3. While MLP is typically used as a retrospective heuristic, it can also be helpful to see current transition periods and view how to assist transition when used with additional sustainability transitions heuristics in transition management and strategic niche management.

Loorbach et al. (2017) highlight that there are several forms of transition, with often a chaotic phase as the incumbent regime is destabilised and new niche socio-technology systems try to break through as shown in Figure 3.5.

Figure 3.5 – The breakdown and build-up of existing and new socio-technical systems



(Source: Loorbach et al., 2017. Republished with permission of Annual Reviews via CCC)

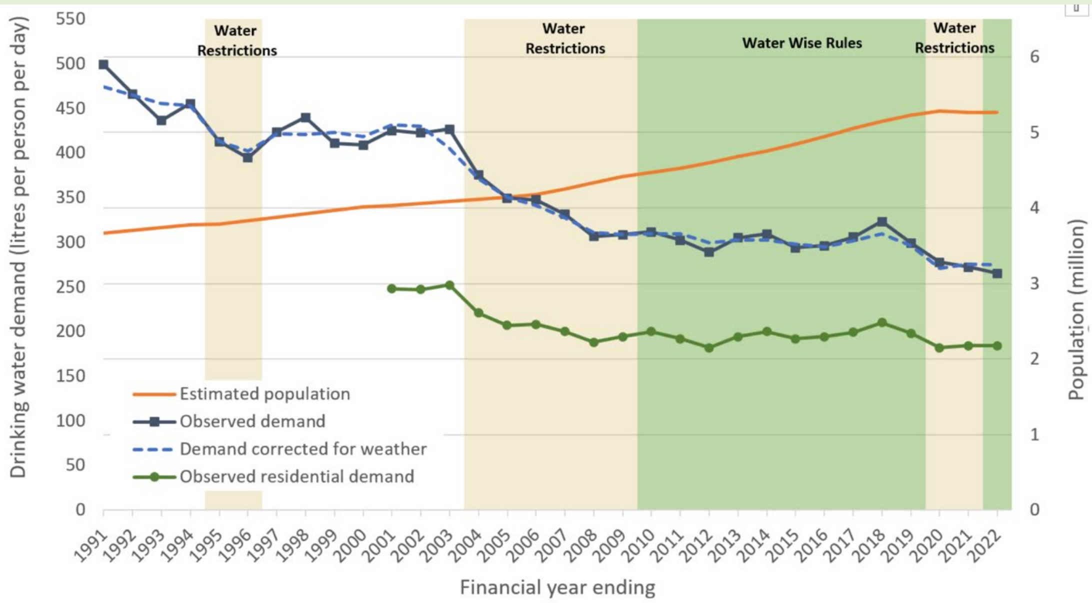
Interestingly in the water and energy sectors, where IRP concepts have been applied such as in Australia, the incumbent LTS has not been 'replaced' as such but rather smaller-scale distributed socio-technical systems have been embedded as part of a 'hybrid system', as noted in Section 3.1 and outlined in Box 6.

For example, water efficient taps and showers, rainwater tanks and on-site recycled water systems in the water industry and efficient light bulbs and fridges, solar panels and wind turbines in the electricity industry. In UOW, this is analogous to maintaining large-scale collection of MSW red-bin residual waste and/or separated organics and extraction/treatment of organics through large centralised MBT facilities or composting, but in combination with other solutions. For example, more localised household composting, on-site dehydrators for clusters of commercial cafes and restaurants, and precinct scale on-site AD for larger-scale commercial cafes or MUD precincts where it makes sense to do so (Turner et al., 2017).

Box 6 – MLP alignment and a unique window of opportunity for water

MLP literature often indicates that the transition of an industry or sector can take decades. However, the shear depth and duration of the Millennium Drought in Australia (lasting for more than a decade) provides one example where the landscape, regime and niche levels aligned to such an extent that a paradigm shift in water service provision was achieved in a relatively short period. This resulted in a significant and sustained drop in urban water usage (as illustrated in the Figure below) and the creation of a hybrid system with efficiency and source substitution at multiple scales being embedded within the incumbent supply system, which was becoming less reliable due to climate impacts on the inflows to the dams (Turner et al., 2016b).

Figure – Historical drop in Sydney water usage 1991 – 2022 (L per person per day)



(Source: Sydney Water, 2022)

This kind of naturally induced window of opportunity is less likely to occur in essential services such as the waste industry, which will require greater emphasis on careful policy planning and alignment to instigate such a paradigm shift, and the use of planned transition actions as indicated in transition management and strategic niche management (see below). Without the sense of urgency instigated by the Millennium Drought for water, the much-needed transition in waste, specifically UOW, is likely to take much longer.

3.4.3 TRANSITION MANAGEMENT (TM)

TM was developed by Rotmans, van Asselt and Kemp in their ground-breaking research (2000; 2001), and introduced as official government policy in the fourth National Environmental Policy Plan in the Netherlands (Rotmans et al., 2007). The plan broke with traditional policy and practices, creating space for innovative policy using TM (Loorbach & Rotmans, 2010).

Sustainable transitions require changes in socio-technical systems and broader societal systems, such as beliefs, values and governance. These broader societal changes need to co-evolve with socio-technical change. Hence, TM has been developed as a practical multi-level model of governance, aiming to help shape processes of co-evolution towards sustainability goals using visions, transition experiments and cycles of learning and adaptation. It aims to help societies transform gradually through cycles of reflexivity, using a simple guiding process, which helps create stepping stones for further change. It combines the advantages of incrementalism with objective based long-term planning (Kemp et al., 2007).

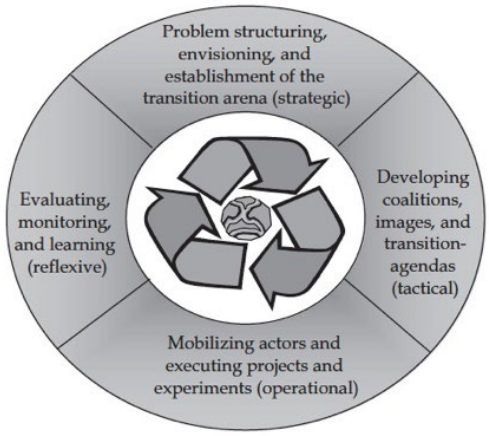
To manage transitions, key basic principles are required (Rotmans et al., 2001), such as: dealing with uncertainties (e.g. use scenarios); keeping options open and dealing with fragmented policies (e.g. stimulate knowledge, technological change, pursue innovation and incremental improvements, paying attention to relevant actors); having a long-term orientation to aid short-term policies; keeping in mind international change processes and finding solutions at the appropriate scale; and having specific tasks for the government (e.g. stimulate, mediate, broker services, create the right conditions, enforce laws and engage in steering).

These principles have been translated into simple activities and are illustrated in a TM framework shown in Table 3.4 (Loorbach & Rotmans, 2010), with reflexive activities related to all three being an integral part, not done afterwards or detached. These include: (i) structure the problem in question and establish and organise a transition arena; (ii) develop a transition agenda, sustainability images and derive the necessary transition paths; (iii) establish and carry out transition experiments and mobilise the resulting transition networks; and (iv) monitor, evaluate and learn lessons from the transition experiments and, based on these, make adjustments in the vision, agenda and coalitions.

Importantly, according to Loorbach (2010), these four activities within the TM framework can be applied at various scales and subsystems levels. For example, the future of biomass can be a tactical activity within the context of the energy transition debate. Within the biomass transition, different flows of biomass or competing technologies will be tactical activities. Examples at different scales of TM investigation are provided by Rotmans et al. (2007) at national, regional and project levels.

Table 3.4 – TM framework

Types/ focus	Problem/ scope	Time scale	Activity level
Strategic/ Culture	Abstract/ societal system	Long-term (30 years)	System
Tactical/ Structures	Institutions/ regime	Mid-term (5–15 years)	Subsystem
Operational/ Practices	Concrete/ project	Short-term (0–5 years)	Concrete



(Adapted from Loorbach, 2010. Republished with permission of John Wiley & sons via CCC)

3.4.4 STRATEGIC NICHE MANAGEMENT (SNM)

SNM was initially developed to understand why some sustainable technologies never leave the research and development stage and effectively fail while others succeed (Elzen et al., 1996; Schot et al., 1994). Further adapted by Kemp et al. (1998) and Mourik and Raven (2006), it is commonly defined as the process of purposefully creating and managing niches for promising new technologies through real life experiments (Loorbach & Raak, 2006). It involves the creation, development and controlled phase-out of protected spaces for such technologies by means of experimentation, with the specific aims of both learning about the desirability of the new technology and enhancing development, and the rate of application of that new technology (Kemp et al., 1998). The process consists of five key phases (Kemp et al., 1998; 2001; Weber, 2003) including (i) choice of technology, (ii) selection of experiment, (iii) set up of experiment, (iv) scaling up of experiment and (v) breakdown of protection. Across these phases a number of specific actions and guidelines have emerged together with warnings of potential dilemmas (Schot & Geels, 2008; Twomey & Gaziulusoy, 2014).

While SNM was initially used retrospectively to analyse historical case studies and often single technologies, it has subsequently been seen as a tool to help drive transition of specific technologies and groups of technologies, which should be done through the use of multiple interactive and supporting experiments (Mourik & Raven, 2006). For best results in managing emerging innovative socio-technical systems, it is important to focus not just on the niche, or the regime, but their interplay through the interaction of TM and SNM (Loorbach & Raak, 2006; Mourik & Raven, 2006). While TM and SNM are different approaches and come from different theoretical backgrounds, they are highly complementary (Loorbach & Raak, 2006). By carefully crafting multiple experiments for several technologies and framing this within the TM strategic, tactical, operational and reflexive context there is potentially greater opportunity to share insights, build on opportunities and break barriers to innovative socio-technical systems being managed and breaking into an existing incumbent regime (Loorbach & Raak, 2006).

The process aims to assist in tackling barriers for new technology, such as:

- **Technical** – lacks technical stability, performance or complementary technologies.
- **Government policy and regulations** – does not fit existing laws and regulations.
- **Cultural** – does not fit user/societal preferences and values.
- **Demand** – does not fit user demands (e.g. it is too expensive).
- **Production** – does not fit firms' expectations about what the user wants, or the new technology is expected to compete with firms' core products, meaning firms are reluctant to invest in large-scale production and so does not benefit from economies of scale.
- **Infrastructure and maintenance** – not yet supported by infrastructure or maintenance networks.
- **Undesirable societal and environmental effects** – solves problems but may cause new ones (Mourik & Raven, 2006).

Many of these barriers are already being observed for innovative UOW socio-technical systems emerging in the Australian and specifically NSW and Sydney context. From case study interviews with practitioners and vendors involved in new UOW technologies, significant barriers are being experienced across virtually all the barriers highlighted. These barriers including for example a lack of policy and regulation on end products for dehydrators and AD, which is creating uncertainty about their permissible use. It also potentially including unintended negative impacts, such as waste to water devices discharging to sewers and potentially contributing to sewer blockages as well as loss of nutrients (Turner et al., 2017; 2018).

3.5 COMBINING INTEGRATED RESOURCE PLANNING, SYSTEMS THINKING & SUSTAINABILITY TRANSITIONS LENSES

IRP provides a well-established practical framework for planning, analysis and decision-making of essential services such as water and energy. It has assisted such industries in the transition to more sustainable practices, such as the move towards more adaptive hybrid systems. Such systems specifically include efficiency/avoidance and alternative smaller-scale distributed systems as well augmentation of existing LTS. This is achieved through clearly establishing (adapted from Turner et al., 2010a):

- The **system** and **boundary** of analysis to be investigated, the key **stakeholders** that need to be involved, the core **services** and **objectives** to be fulfilled and overall **broad context** of the jurisdiction under scrutiny (conducted within IRP – Step 1).
- The **detailed context** of the complex **socio-technical system** under investigation with **available data and information** through both top-down **holistic synthesis** and bottom-up **analytical disaggregation** as well as establishment of the **factors** potentially affecting historical, current and **forecast** resource use/generation (IRP – Step 2).
- The relevant **context-specific solutions** needed, with **efficiency/avoidance** and **multiple scales** of solutions brought to the fore, assessed against the key established planning **objectives and criteria** with **consistent boundaries and assumptions** and recognition of potential positive and negative **impacts** and **interconnections** with other systems (IRP – Step 3).

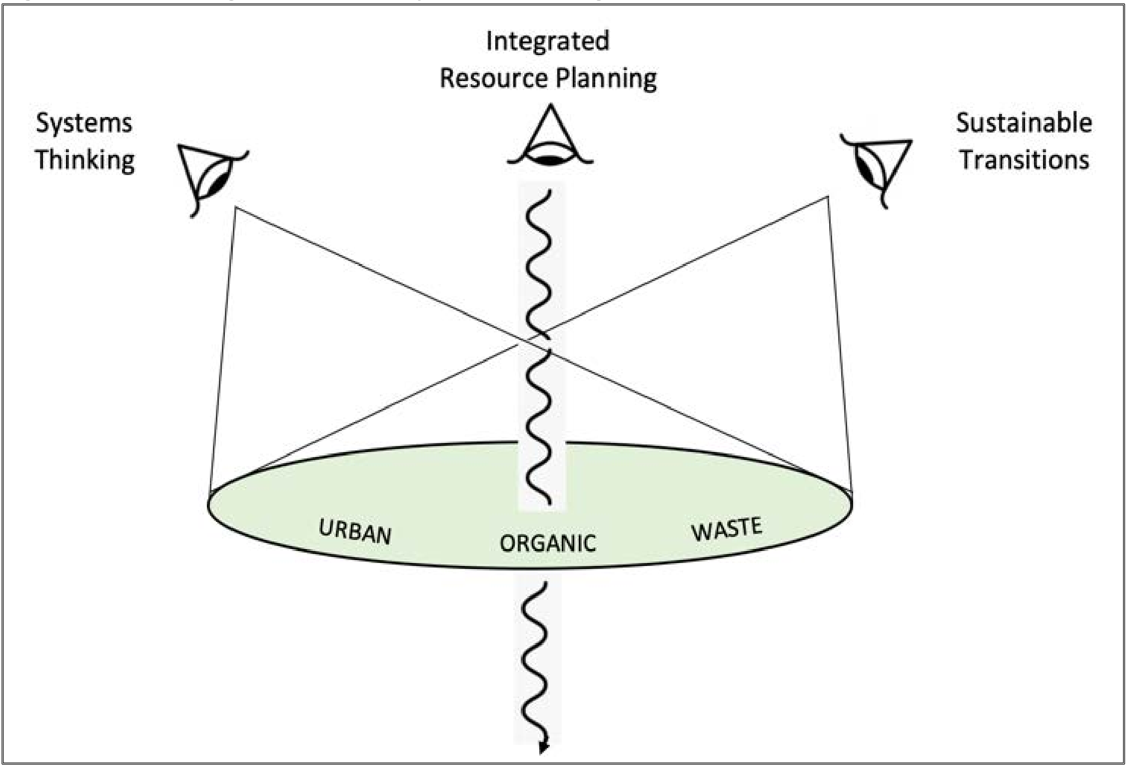
This as well as piloting and implementation (IRP – Step 4) and monitoring and evaluation (IRP – Step 5) of the programs implemented to assist in **ongoing learning** and **adaptive management**.

These key features align well with some of the gaps and opportunities identified in Section 2.5 and summarised in Table 2.1. Hence, IRP, which appears to have had limited application in waste management and none in the new emerging UOW management sector, has significant potential in filling some of those gaps and opportunities identified and can help improve UOW planning, analysis and decision-making. Due to the complexity of the UOW sector, the rapid emergence of associated innovation and the rapidly changing policy environment, the systems thinking concepts and methods identified in Section 3.3 could help strengthen IRP practice and also help fill specific gaps, as could sustainability transitions discussed in Section 3.4.

While both systems thinking and sustainability transitions are both highly developed approaches with significant theoretical foundations, it would appear best to use IRP as the core lens and strengthen/augment it with systems thinking and sustainability transitions lenses as illustrated in Figure 3.6. This due to IRP's:

- long-established use and demonstrated benefits of application specifically in essential services (namely water and energy)
- highly 'flexible' and 'practical' step-by-step approach focused specifically on how to achieve sustainable and efficient resource planning.

Figure 3.6 – IRP augmented with systems thinking and sustainable transitions lenses



As identified in Section 3.3, IRP emerged in parallel to systems thinking and thus whilst inherently a systems thinking approach, it does not necessarily use systems thinking terminology or tenets to the same extent. Shared concepts and tenets range from actively considering systems, their boundaries and interactions to focusing on the function or service of the system and the potential for multi-functional objectives with emergent functionality not necessarily known at the beginning of an investigation. Also useful are the ways of viewing the system both as a whole and as disaggregated socio-technical systems, subsystems and components. This is particularly useful in UOW management when thinking through the value chain of food and other UOW from farm to consumer fork and then on to the respective waste streams and resources that can be reused before (the least preferred) disposal. This helps to break the common, narrow view of UOW as merely residential food waste and garden organics generated through the MSW stream. Figure 3.7 provides a simplified illustration of the food and other UOW value chain, which identifies outputs from the residential MSW and C&I subsystem sectors (i.e. food waste, fats, oils and greases from grease traps, used cooking oils, wastewater and trade waste) not typically considered together under the organics umbrella when viewed from the waste management industries perspective. This form of intellectual construct is commonly used in soft systems methods as a visual 'device' to help think through and engage stakeholders in complex systems (refer to Table 3.2).

Incorporating specific concepts from sustainability transitions (discussed in Section 3.4) could also provide significant benefit, such as being aware of and specifically bringing to the attention of planners and decision-makers:

- the nuance of **landscape drivers** in terms of potential **system shocks** (e.g. China Sword, COVID-19, mixed waste organic outputs regulation changes, introduction of organics targets) and varying **trends** (e.g. population rise, urban densification, growth in the proportion of MUDs)
- the potential for **windows of opportunity** that can assist in accelerating transformative system change if managed through processes such as TM
- **innovation** on the horizon that might cause positive and/or negative **disruption** to the system
- the risk of **LTS lock-in** and **innovation and adaptive management lock-out** due to the established nature of the incumbent system
- the stability of the current regime and **potential for change**
- the level of **uncertainty** and thus potential benefit of using **scenario planning** to deal with system shocks and varying trends.

Also similar to systems thinking, sustainability transitions provide a useful view of the system but from an alternative perspective, as illustrated in Figure 3.8 for UOW management. This illustrates:

- the MLP layers of the landscape (and associated drivers), the current socio-technical regime (with incumbent LTS) and niche level with various innovative socio-technical solutions of various scales emerging and vying for inclusion in the associated emerging market
- the window of opportunity (or chaos) opening up due to various landscape drivers and niche innovation putting pressure on the current incumbent LTS, which will have a

propensity to lock-in due to existing rules, practices, sunk investment and vested interests

- the use of MLP to view the historical and current context and adaptive management influenced TM approach to help proactively consider ways to transition/transform the existing system using the momentum of the window of opportunity and potential designed experiments through SNM
- the futures and transformation orientation, including consideration of potential pathways to get there.

Hence, from examining IRP, systems thinking and sustainability transitions and their linkages, there are various core concepts and methods within each that when the lenses are combined have the potential to improve UOW management planning, analysis and decision-making and the IRP approach itself. Many of these concepts and methods overlap, especially between systems thinking and IRP. This effectively helps to expand and deepen our theoretical understanding of each key concept in IRP and how they can be more effectively incorporated into IRP practice. And with sustainability transitions, some key concepts and methods are explicitly added that are not specifically considered in systems thinking or IRP.

Figure 3.9 highlights the core concepts and methods and how some of these:

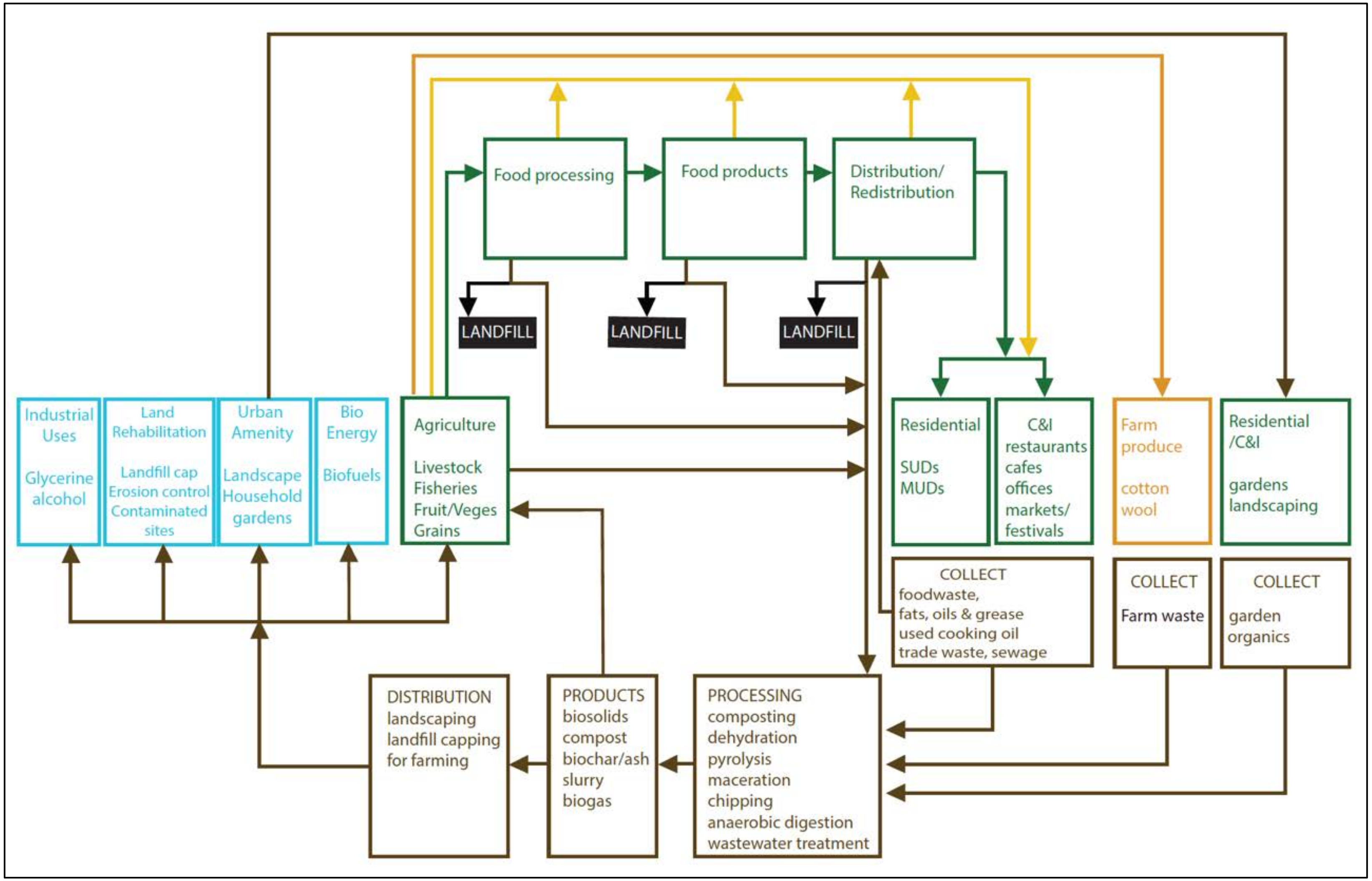
- are the same (i.e. the importance of focusing on service or function)
- are similar (i.e. needing to consider uncertainty and use, for example, scenarios to do so)
- add a new useful dimension to the process of inquiry (i.e. explicitly considering innovation, as in the case of sustainability transitions).

Table 3.5 draws together:

- the gaps and opportunities in current waste management approaches identified in Section 2.5 Table 2.1.
- the core IRP steps of relevance to those gaps and opportunities (i.e. Steps 1 to 3)
- the IRP sub-step focus (i.e. identifying the system and boundary)
- the existing strength of IRP based on the experience of water
- additional lenses that could assist in strengthening/augmenting IRP and examples of 'how' that might be achieved (i.e. greater linkage with systems theory or using an identified method from sustainability transitions).

The next two Sections (Part III) focus on Sydney. First looking at the characteristics of the city that affect UOW in Section 4.0 and then in Section 5.0 at a series of Sydney-based nested case studies at various scales. The case studies aiming to specifically fill gaps in knowledge on UOW streams and quantities as well as potential innovative solutions available.

Figure 3.7 – Simplified conceptualisation of the urban food and broader organics waste system



(Source: Turner et al., 2019)

Figure 3.8– Conceptualisation of sustainability transitions for UOW

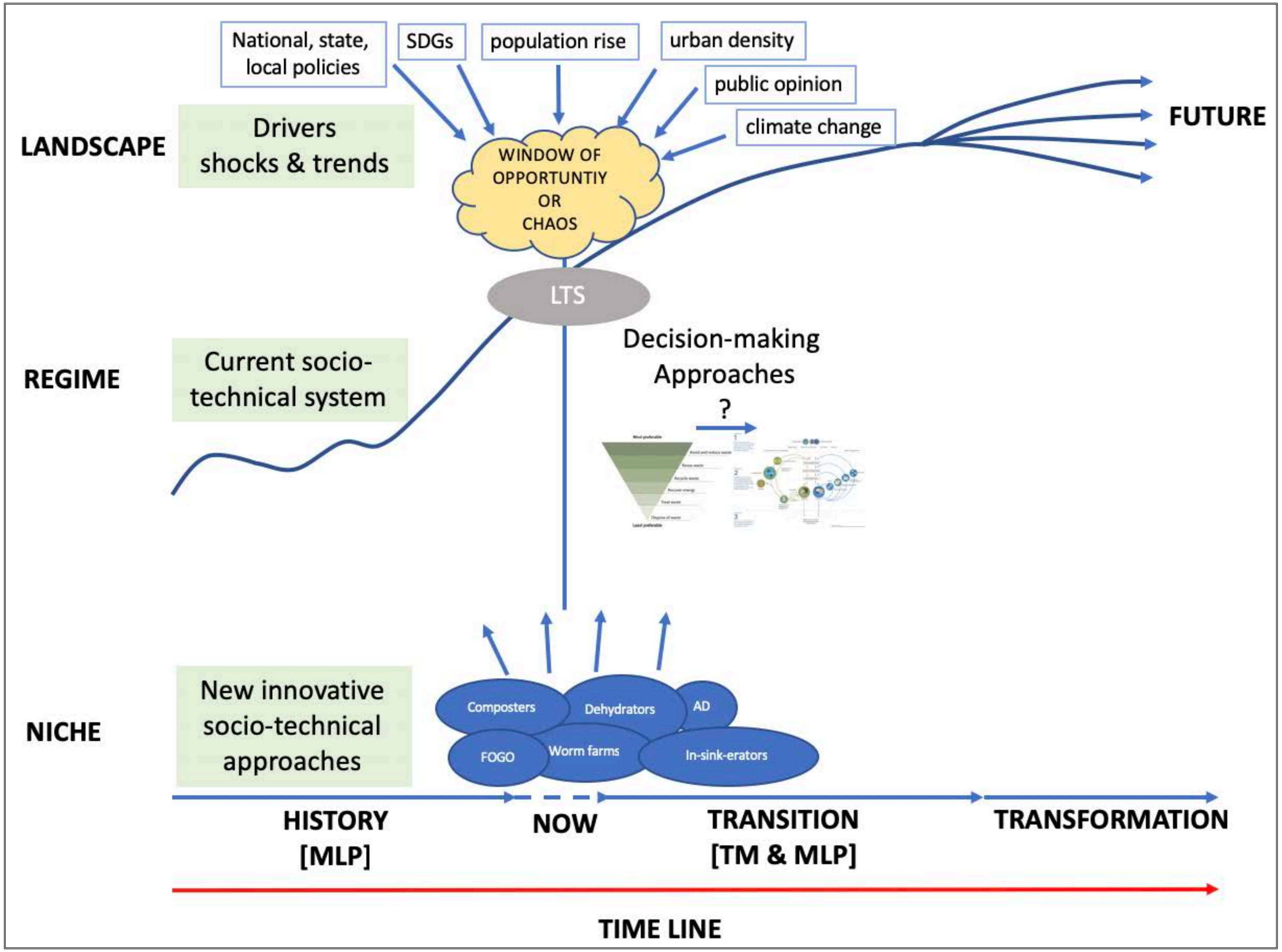


Figure 3.9 – Conceptualisation of the core IRP, systems thinking and sustainability transitions key concepts and methods

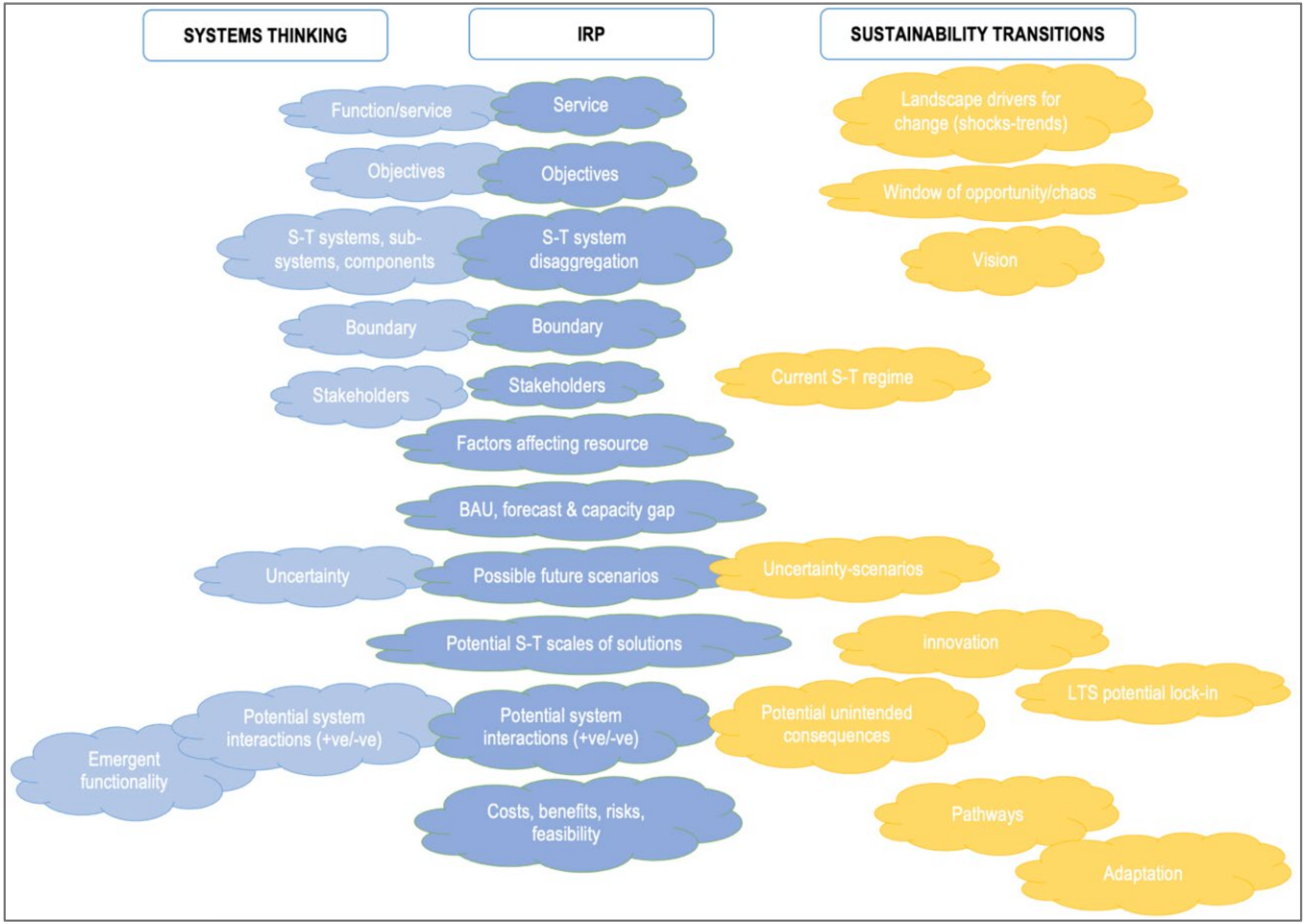


Table 3.5 – Summary table of gaps and opportunities together with IRP steps, current strengths and examples of how to potentially strengthen

Waste management gaps & opportunities in Table 2.1	**IRP Step/Sub-step focus**	**Existing IRP strength**	**Potential to strengthen**	**Examples of how (identified in Section 3)**
A need for approaches that better consider & incorporate: 1. a broader & deeper **socio-technical systems perspective** 2. multiple & often conflicting **objectives** & **criteria** specifically relevant to UOW characteristics 3. the **broad context** of the jurisdiction being investigated & associated **drivers & pressures** **4. cross-sectoral impacts & trade-offs** 5. the diverse **stakeholders** involved in generating & managing UOW to more effectively account for	**1 – Plan & frame**			
	Define systems & boundaries	●●●	Systems thinking	Stronger linkage with shared concepts, i.e.: - hierarchy of interacting systems (systems, subsystems & components) with a mix of open & closed boundaries that interact with their environment to varying extents (especially useful in UOW with potential cross-sectoral impacts and trade-offs) *- use soft systems models (e.g. visual aids) as intellectual constructs, 'devices', to help think through & visualise complex systems (& engage stakeholders)
	Consider diverse stakeholders	●	Systems thinking	Stronger linkage with shared concepts and importance of, i.e.: - identifying & categorise stakeholders through PSMs like stakeholder analysis to - help think through the social features of new emerging socio-technical systems - appreciate multiple social perspectives, values & preferences Specifically from third wave systems thinking strengthen by: - ensuring inclusiveness & dealing with power (important in UOW, especially Australia, due to fragmented & privatised industry) *- use soft systems models (e.g. visual aids) as intellectual constructs, 'devices', to help think through & visualise complex systems & engage stakeholders
	Clarify the broader context	●	Sustainability transitions	Use sustainability transitions to more effectively view the broad context, i.e.: - MLP visualisation of system (landscape, regime & niche) & futures & innovation - consider drivers for change, windows of opportunity and pathways to get there

Waste management gaps & opportunities in Table 2.1	IRP Step/Sub-step focus	Existing IRP strength	Potential to strengthen	Examples of how (identified in Section 3)
stakeholders & **social perspectives**				- consider issues of potential LTS lock-in & adaptive management & innovation lock-out
6. **MCDA features** that work through objectives & criteria, the specific context & array of potential solutions **iteratively** (i.e. value-context-alternative focused thinking)	Clarify the service provided & goals/ objectives	●●●	Systems thinking	Stronger linkage with shared concepts, i.e.: - socio-technical systems centred around function or service, sometimes with emergent multi-functionality/objectives (this again useful in UOW with multiple streams of varying characteristics, quality & uses & the potential for conflicting objectives that need to be considered)
	2 - Analyse			
7. the **detailed context** of the jurisdiction to help inform decisions despite **data gaps**	Conduct resource disaggregation	●●●	System thinking	Stronger linkage with shared concepts, i.e.: - analytical synthesis & disaggregation to see systems as a whole as well as component parts with various interactions
8. a broader **network of complementary options** of varying scales	Conduct disaggregated forecasting	●●●	Systems Thinking Sustainability transitions	As above through stronger linkage with systems thinking concepts, i.e.: - analytical synthesis & disaggregation to aid forecasting. Also use sustainability transitions to more effectively forecast, i.e.: - include futures & innovation focus (especially useful in UOW with the need for long term planning & inclusion of innovation to aid in scenario planning)
9. **preservation of resources/prioritisation of avoidance**	Conduct mapping & visualisation	-	Systems thinking	Stronger linkage with shared concepts & methods, i.e.: *- use soft systems models (e.g. visual aids) as intellectual constructs, 'devices', to help think through & visualise complex systems & engage stakeholders
10. the risk of **LTS lock-in** & **adaptive management** & **innovation lock-out**	**3 – Develop & assess**			
	Options identification	●●	Systems thinking	Stronger linkage with shared concepts, i.e.:

Waste management gaps & opportunities in Table 2.1	**IRP Step/Sub-step focus**	**Existing IRP strength**	**Potential to strengthen**	**Examples of how (identified in Section 3)**
11. integration of **GIS visualisation** techniques to assist in better understanding complex waste management systems & **engage stakeholders** to improve decision-making	& development		Sustainability transitions	- based on service/function, disaggregation & system interactions identify & develop options - *use soft systems models (e.g. visual aids) as intellectual constructs, 'devices', to help think through complex systems and more effectively engage stakeholders Also use sustainability to aid: - incorporating futures and innovation focus - TM and SNM to consider stakeholder engagement (i.e. arena) & stages of innovation & transition (i.e. feasibility/demonstration).
	Cost & assess options	●●●	Systems thinking	Stronger linkage with shared concepts & methods, i.e.: - system service/function, emergent functionality & interconnections (useful in UOW decision-making to be able to observe cross-sectoral benefits, unintended impacts & trade-off considered through methods using MCDA features)

PART III:

CASE STUDY

ANALYSIS

4 SYDNEY

Section 1.0 provided an overview of Australia, the waste and policy context, including that affecting NSW, and high level waste/UOW statistics. Here I provide more detailed context on Sydney, the largest city in Australia, and some of the key characteristics that will impact UOW, including planning, analysis and decision-making. Using basic concepts from IRP, outlined in Section 3.0, I first look at the boundary of the city and highlight the inconsistencies between various agency definitions and sectors managing planning and UOW systems. This lack of alignment complicating even basic statistics about the city. I then go through more detailed characteristics. Firstly I provide details of the significant population growth and urban densification, which will have a major impact on urban form, resource use, waste generation and essential service provision. I then highlight the significant growth in MUDs and mixed use/precincts which will likely affect UOW forecasts and how the highly dated C&I data makes it difficult to ascertain UOW generation in the non-residential sector. I also give examples of government supported organics waste management programs and other interventions that have been implemented over the last decade and highlight the lack of collective knowledge of these and smaller-scale socio-technical systems which will affect overall UOW generation and potential savings. Finally, I draw together data on other UOW streams such as wastewater biosolids, fats, oils and grease from grease traps and used cooking oils, not typically considered with food waste and garden organics management, despite their omnipresence in the urban environment. I also reiterate the lack of focus on these streams and publicly available data, which limits cross-sectoral analysis into potential benefits and unintended consequences. The gaps and opportunities identified highlight the need to improve Sydney based UOW data measurement, collation and analysis, which is addressed in part by the Sydney-based nested case studies summarised in Section 5.0.

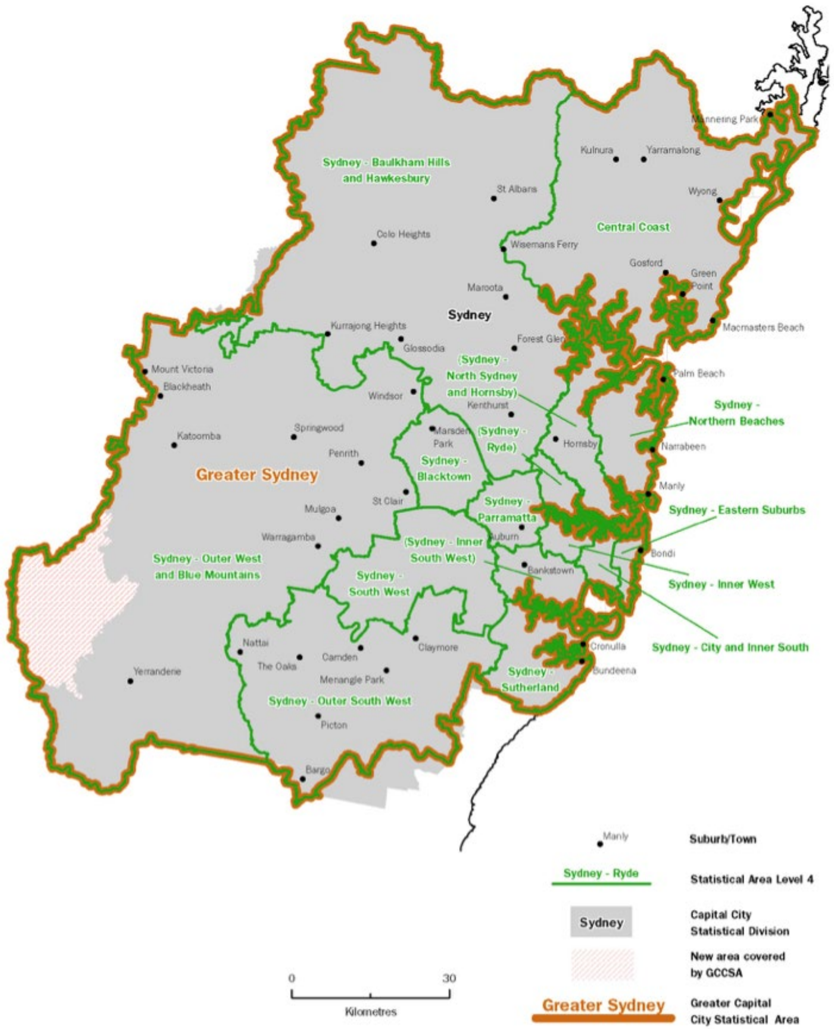
4.1 GEOSPATIAL BOUNDARIES

Sydney, currently one of the two most populous cities in Australia, has various geospatial boundaries. These boundaries are dependent on the authority defining them. Due to the NSW state government forced council amalgamations in 2016, of which a few did not eventuate due to legal battles (Saulwick, 2017), some boundaries and administrative groups have shifted in recent years. These boundary changes complicate basic boundary definitions of the city and the use of some of the available historic data for analytical purposes, including those relating to waste management for which councils are a key stakeholder.

The ABS defined Greater Capital City Statistical Area (GCCSA) currently covers 34 of the 128 council LGAs within NSW. The Greater Sydney Commission (GSC) planning boundary is the same as the GCCSA except it omits the Central Coast to the north east, refer to Figure 4.1. The waste and water/wastewater boundaries for the city, discussed in Sections 4.3 and 4.4, are significantly different again. Such differences in boundaries make it difficult to enable meaningful cross sectoral use/comparisons of various historical and current datasets and often ambiguity when defining basic statistics about Sydney. The GSC boundary provides a useful focal point for planning and essential services discussions.

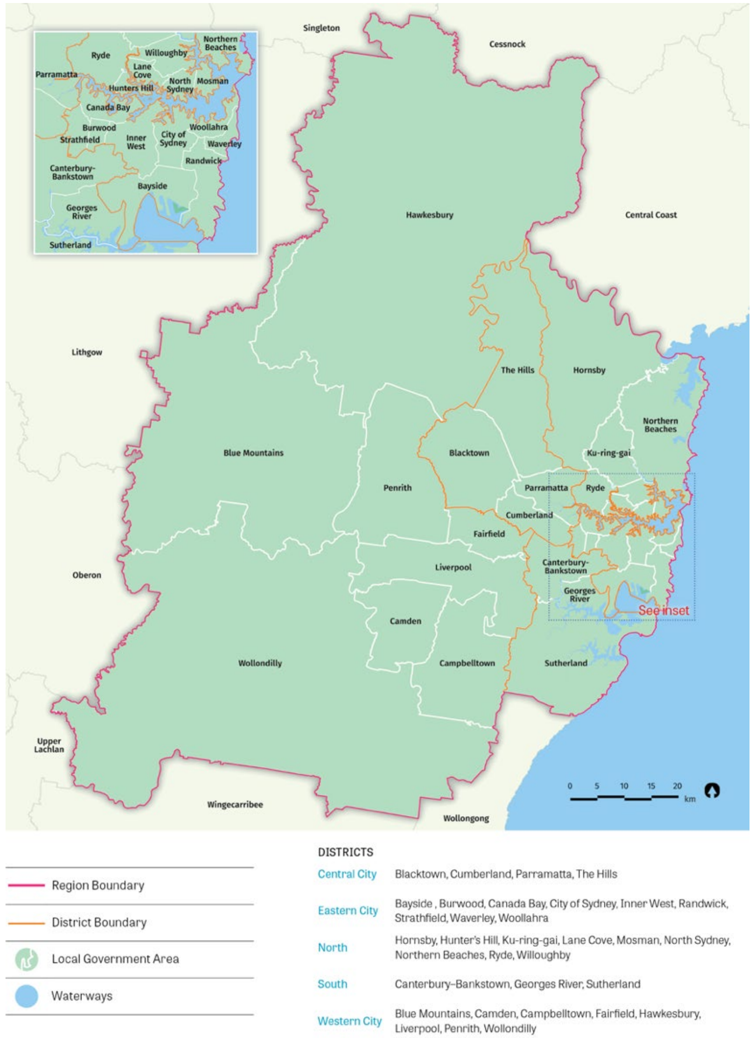
Figure 4.1 – Greater Sydney boundaries

(a) ABS Greater Capital City Statistical Area



(Source: ABS, 2021)

(b) GSC Sydney and District boundaries



(Source: GSC, 2018a)

4.2 GROWTH & URBAN DENSIFICATION

Whilst Australia is a relatively small developed country, with a population of just over 25 million (ABS 2022), it represents a microcosm of many of the global issues at hand, such as relatively high population growth/immigration (Productivity Commission [PC], 2010; PoA, 2017), rapid urban densification (SOE, 2021) and associated high resource use and wastage (OECD n.d). The majority of the population live in major coastal cities such as Sydney and Melbourne (Chen & McAneney, 2006), where future growth and urban densification are planned and already occurring (Coleman, 2016). Such growth is expected to push both Sydney and Melbourne to mega city populations of 10 million before the end of the century (McGregor Coxall, 2021). This will put significant pressure on essential services including waste management.

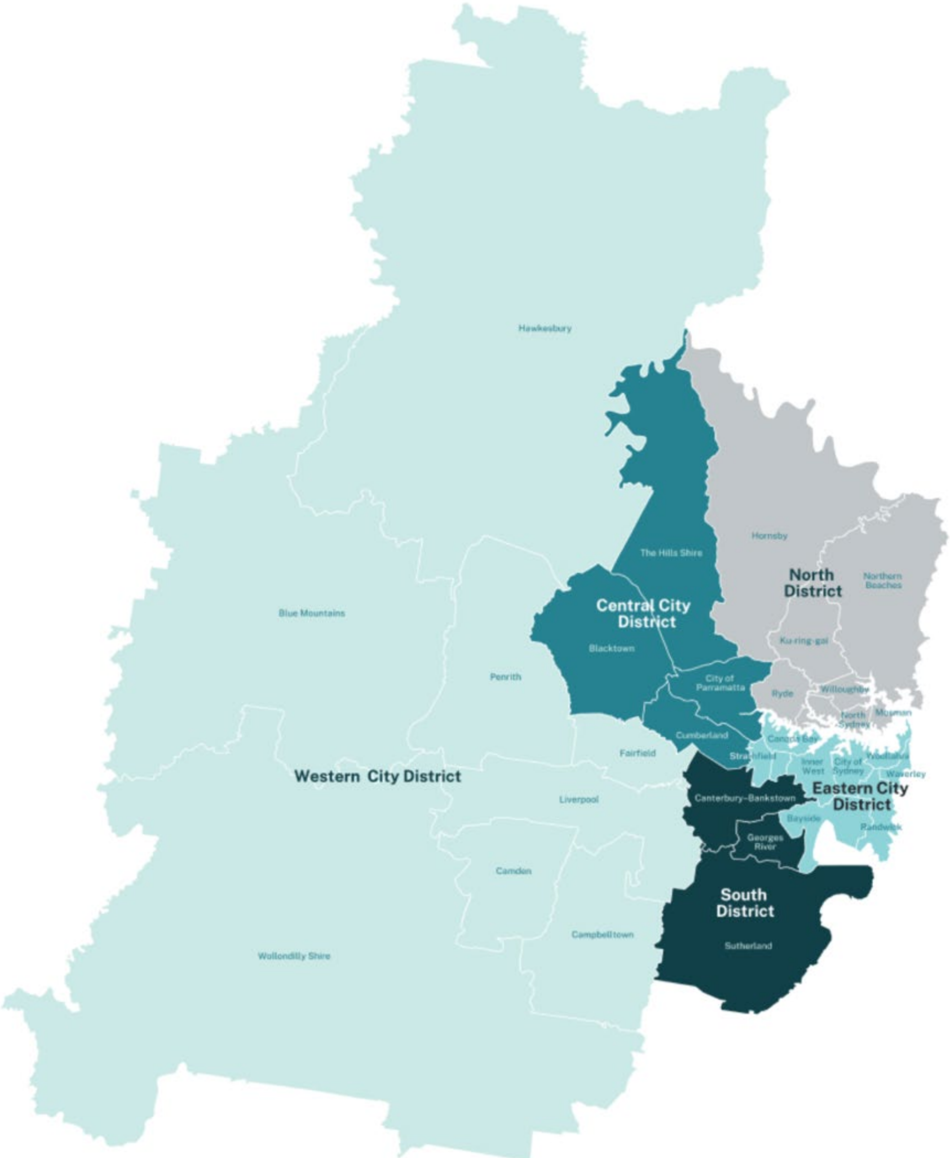
4.2.1 POPULATION & HOUSING PLANNING GROWTH & DENSIFICATION

In 2015 the GSC[11] was established as an 'independent' NSW government agency responsible for land use planning across Sydney. Strategic plans developed by the GSC for Sydney, which are significantly reshaping the character and density of the city, include:

- 'A Metropolis of Three Cities – the Greater Sydney Region Plans' (GSC, 2018a)
- The five 'District Plans' across the city covering the North, East, South, West and Central areas (GSC, 2018b; 2018c; 2018d; 2018e; 2018f), as shown in Figure 4.2.

[11] In 2022 the GSC expanded its remit beyond Sydney to Newcastle and the Central Coast to the north and Illawarra-Shoalhaven to the south. It is now called the Greater Cities Commission with a focus on the strategic planning of the Six Cities Region in NSW (https://greatercities.au/about-us - accessed 01/05/23)

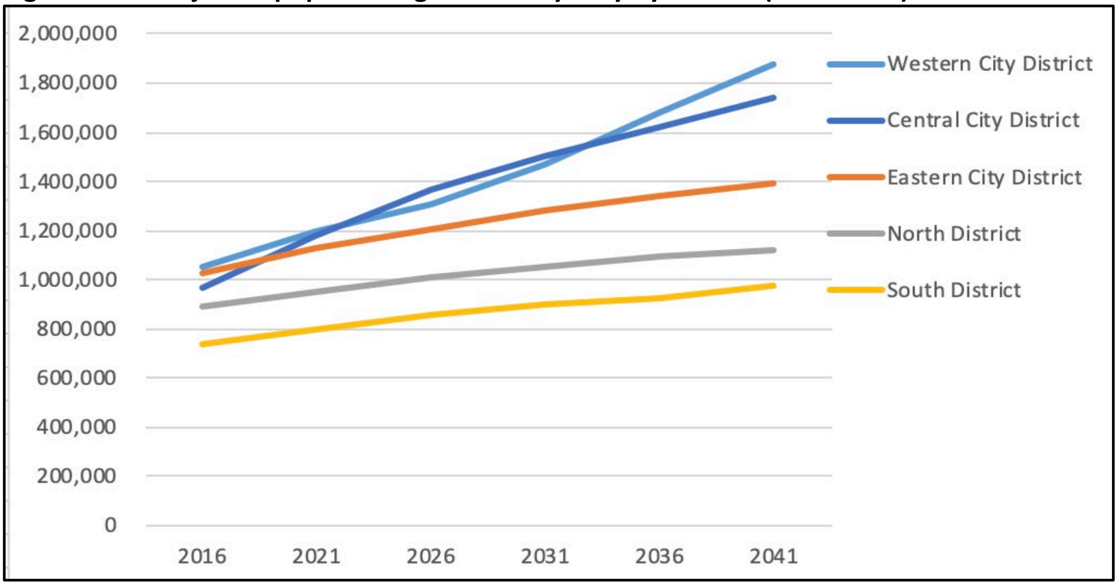
Figure 4.2 The 5 GSC District Plans



(Source: NSW Planning, n.d.)

According to the 2016 census (ABS 2016), NSW as a whole had a population of 7.7 million and the GCCSA a population of just over 5 million (i.e. 65% of the population in only 2% of the area of the state). Based on the GSC plans/projections, which exclude the Central Coast (approximately 300,000 people), Sydney is expected to grow to 6.5 million by 2036 and 8 million by the middle of the century (GSC, 2018a). Most of the growth will be in the western and central districts, as shown in Figure 4.3.

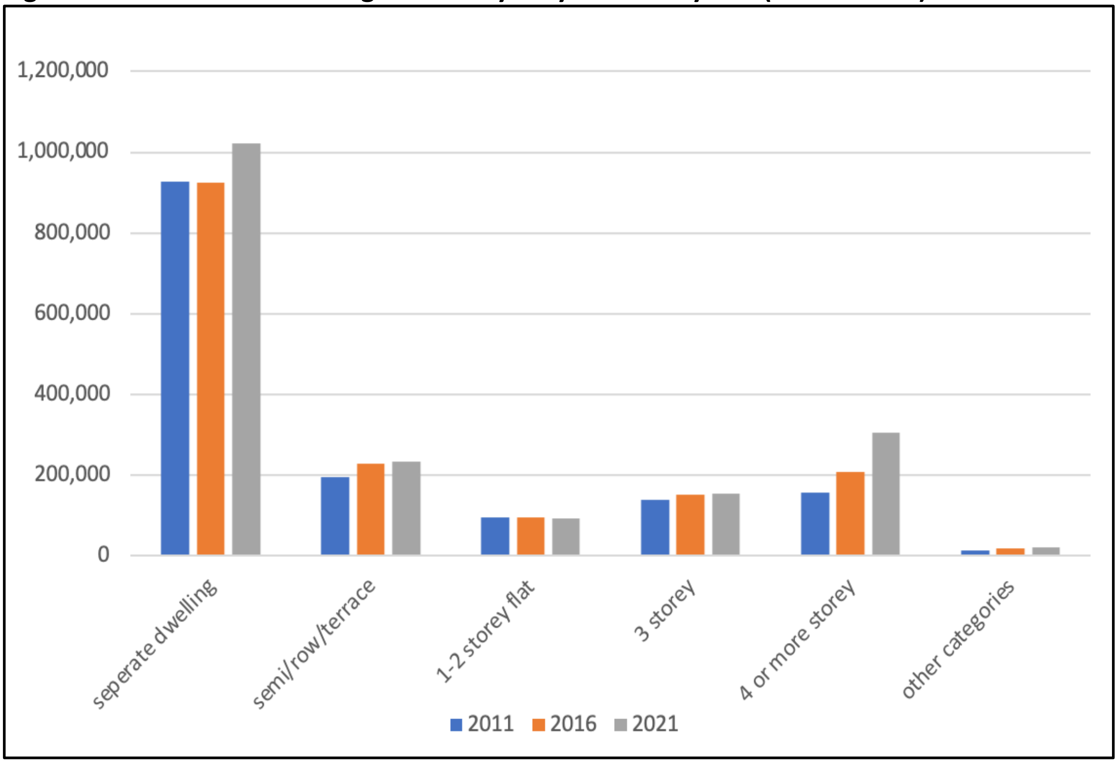
Figure 4.3 – Projected population growth in Sydney by District (2016-2041)



(Source data GSC, 2018a)

Over half of the current GCCSA housing stock are separate (detached) dwellings. As indicated in Figure 4.4, after a slight decline between 2011 and 2016, there was an uptick in separate (detached) dwelling construction. The most significant consistent growth in recent years has been in higher density dwellings of 4 or more storeys.

Figure 4.4 – Growth in housing stock in Sydney in recent years (2011 – 2021)



(Source data ABS 2011; 2016; 2021)

According to census data, the vast majority of growth in recent years has been in forms of 'low', 'medium' and 'high' density dwellings (i.e. not in separate [detached] dwellings) (id, n.d.). However, the definitions of dwelling densities vary significantly between different authorities. This again leads to ambiguity in the interpretation of reported data. For example, the waste industry typically terms separate (detached) dwellings and 'low' density semi/row/terrace dwellings collectively as 'single dwellings' (SD) despite their different character in terms of land area/outdoor space (i.e. gardens). In addition council led waste audits have, until recently, excluded high density dwellings of more than 3 storeys in MUDs analysis, due to concerns over bias in sampling, as further discussed in Section 4.3.3. This exclusion of 'high' density dwellings despite such buildings having been over 10% of the housing stock since the 2011 census and having the highest growth over the past decade.

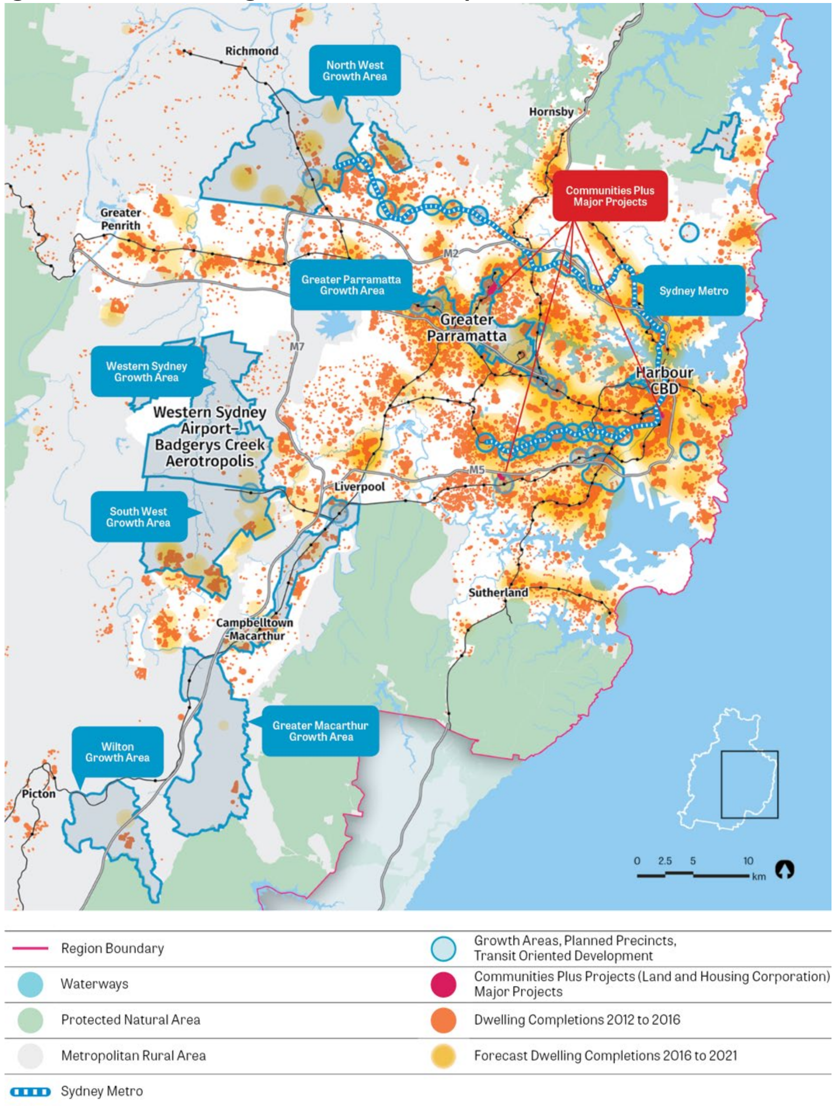
Whilst potentially subject to change, due to changes in state government and associated strategic direction, according to GSC planning, between 2016 and 2036 an additional 725,000 new dwellings will be needed in Sydney, 36,250 per year, to house the projected 6.5 million population (GSC, 2018a). Assuming a further 725,000 new dwellings will be needed after that, for the population of 8 million by 2056, this amounts to 1.45 million new homes in less than four decades. That is, from the turn of the century to the middle of the century Sydney is expected to double in size in terms of housing stock.

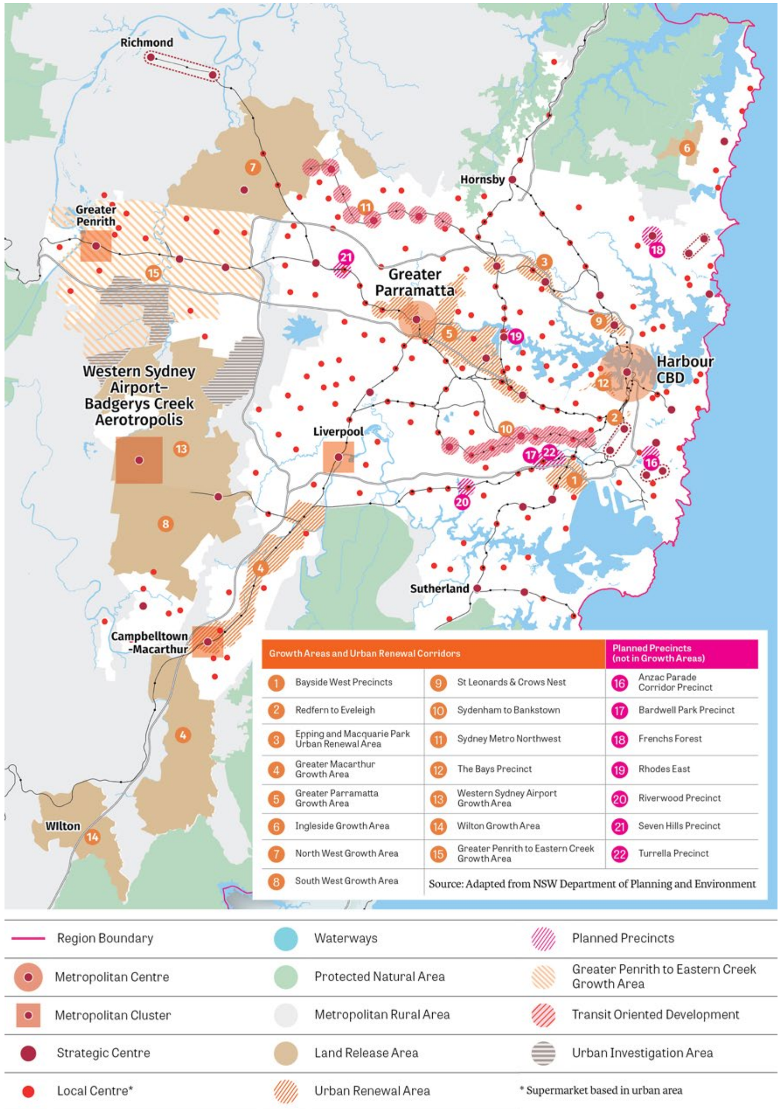
Between 2016 and 2036 the vast majority of homes will be built/developed through planned growth areas/precincts of varying sizes. A significant proportion will be some form of medium and high density housing. Based on the GSC reported plans (GSC, 2018a) over 50 'precincts' are already identified. Many of these precincts will be built along planned transit/urban corridors, and through a combination of:

- state-led strategic planning
- state and council collaborative planning
- state-led rezoning
- council-led rezoning.

Figure 4.5 shows the current and projected growth locations. Figure 4.6 provides examples of traditional detached dwellings and new low density terraces and medium and high density MUDs/precinct developments being constructed with significantly different character.

Figure 4.5 – Planned growth areas and precincts





(Source: GSC, 2018a)

Figure 4.6 – Examples of different dwelling styles/densities

(a) - separate detached dwellings

(b) - terrace dwellings

– medium rise dwellings

(d) – high rise dwellings

Photos: Andrea Turner

Such high growth rates in Sydney and the shift from the predominantly traditional separate (detached) dwellings, often with substantial gardens, to various forms of medium and high density dwellings, will have a significant impact on essential service needs such as water, wastewater, energy and waste. This growth provides both potential for major constraints in delivering those services but also major opportunities to reshape how essential services are provided (i.e. a window of opportunity).

Nearly 20% of all the projected dwellings in Sydney in the year 2036 haven't been built yet and almost 40% of houses anticipated by the middle of the century. Such a significant increase in new housing stock provides a major opportunity to influence how they are developed now. Assuming the same recent trends, that is medium and high density dwellings, Sydney will have a markedly different character, with different service delivery methods needed. For example, for separate (detached) dwellings with gardens versus medium and high density developments with little outdoor space and more concentrated resource and waste management requirements. With over 50 precincts already being built/planned, according to GSC (2018a), the majority medium and high density in character, a focus on how to provide services to those dense urban environments, including UOW management, is needed. This will assist in minimising issues already being observed in dense urban environments such as poor aesthetics, odour, public access issues, safety concerns and traffic congestion in built up areas (NSW EPA, 2019a), as illustrated Figure 4.7.

Figure 4.7- Example of bin issues in medium density urban environments

(Source: NSW EPA, 2019a)

Councils will play a key role in much of the rezoning/development planning and controls of the new developments and subsequent waste management contracts for both existing and new customers. They will therefore play a key role in the future of waste management for the residential sector but could also potentially play a greater role in the non-residential C&I sector, due to the sheer number of mixed use/precincts being developed.

4.3 WASTE

4.3.1 SYDNEY WASTE MANAGEMENT BOUNDARIES

Sydney's waste management boundaries, which have recently undergone realignment, do not easily tie in with other geospatial GCCSA, GSC planning or water/wastewater boundaries. Hence to identify the historical, current and future waste generated and managed in Sydney is complicated.

The NSW EPA identified waste management areas in historical records include the: Sydney Metropolitan Area (SMA), Extended Regulated Area (ERA), and Regional Regulated Area (RRA). However the SMA and ERA have recently been combined and are now called the Metropolitan Levy Area (MLA) and the RRA is now known as the Regional Levy Area (RLA). Outside these areas there are a significant number of non-levied councils that are not included in a levy area, refer to Figure 4.8.

Figure 4.8 also illustrates boundary issues. It provides a comparison of those councils within the MLA (SMA plus ERA) and RLA, for which the NSW EPA has some historical waste data, against:

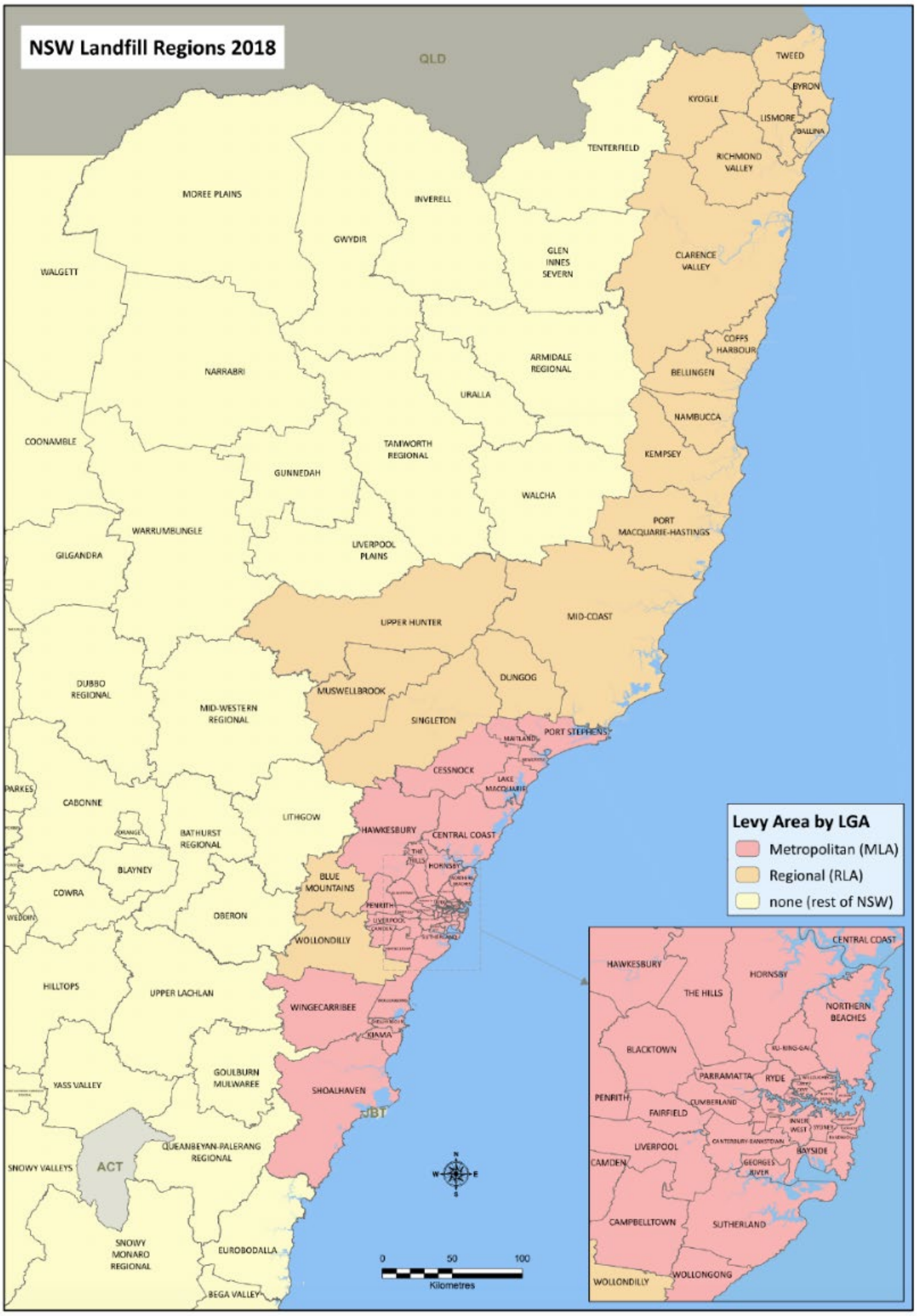
- individual regional organisations of councils (ROCS) [12],
- the five GSC districts plan areas, which provide details on planned growth
- the GCCSA boundary

Each boundary encapsulates a varying arrangement of council LGAs giving for example different population figures for the 2016 census year:

[12] Sydney based ROCs include SSROC, NSROC, WSROC and MACROC, which work together as groups of LGAs to aid in increased procurement power and typically develop strategic waste management plans (i.e. SSROC as mentioned in Box 1) as well as other LGA management requirements.

- SMA – 4,474,485
- GSC – 4,670,448
- GCCSA – 5,005,305

Figure 4.8 – Various waste management boundaries
(a) NSW EPA waste management boundaries



(Source: Rawtec, 2020. Reproduced with permission of author)

(b) NSW EPA waste management boundaries compared with other LGA boundaries

COUNCILS	EPA			ROCS					GSC					GCCSA
	MLA		RLA											
	SMA	ERA	RRA	SSROC	NSROC	WSROC	MACROC	OTHER	EASTERN	SOUTH	NORTH	CENTRAL	WESTERN	
Bayside														
Burwood														
Canada Bay														
Canterbury-Bankstown														
Georges River														
Inner West														
Randwick														
Sutherland Shire														
Sydney														
Waverley														
Woollahra														
Hornsby														
Hunter Hill														
Ku-ring-gai														
Lane Cove														
Mosman														
North Sydney														
Ryde														
Willoughby														
Blacktown														
Cumberland														
Fairfield														
Liverpool														
Parramatta														
Penrith														
The Hills Shire														
Camden														
Campbeltown														
Northern Beaches														
Strathfield														
Central Coast														
Cessnock														
Hawkesbury														
Kiama														
Lake Macquarie														
Maitland														
Newcastle														
Port Stephens														
Shellharbour														
Shoalhaven														
Wingecarribee														
Wollongong														
Ballina														
Bellingen														
Blue Mountains														
Byron														
Clarence Valley														
Coffs Harbour														
Dungog														
Kempsey														
Kyogle														
Lismore														
Mid-Coast														
Muswellbrook														
Nambucca														
Port Macquarie-Hastings														
Richmond Valley														
Singleton														
Tweed														
Upper Hunter Shire														
Wollondilly														

This non-alignment of boundaries complicates the ways in which any waste management data can be used in understanding the historical, current and projected UOW and the ability to be able to utilise other potentially useful cross sectoral data sources for analysis.

The SMA whilst encompassing three less councils, 215,000 less people in 2016-17, has a similar boundary to the GSC which identifies current and planned growth. Hence the SMA is a useful proxy for the GSC area, due to the availability of historical data, to enable high level analysis/comparison of population, growth and waste management.

4.3.2 NSW & SYDNEY GENERAL WASTE MANAGEMENT FIGURES

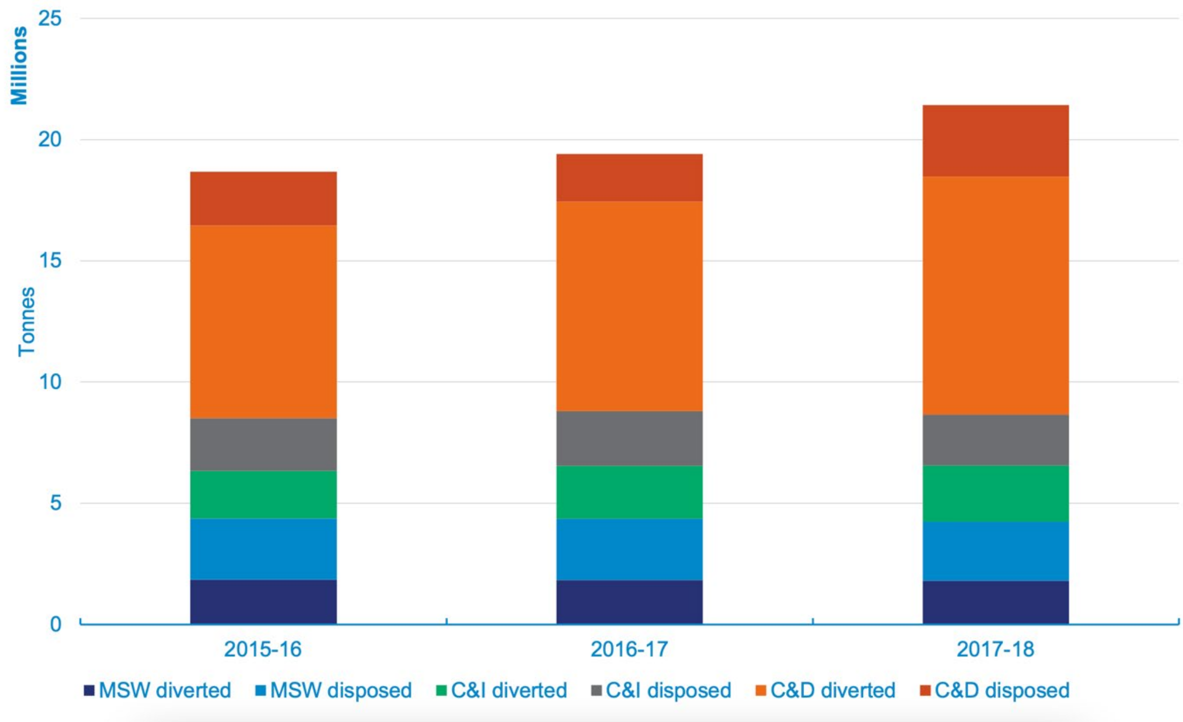
In NSW 19.4 Mt of waste was generated in 2016-17. MSW and C&I representing just under half the mass generated. Similar to national figures, C&D dominated the waste generated due to the significant construction and development in Sydney. However, the majority of the C&D materials were recycled (81%), unlike MSW and C&I waste where only 42% and 49% of the materials generated were recycled, respectively, refer to Table 4.1 and Figure 4.9.

Table 4.1 – Waste generated and disposed in NSW by waste stream (2016-17)

	Generated (Mt)	%	Per capita (t/capita)	Waste recycled (Mt)	%	Waste disposed (Mt)	%
MSW	4.36	22	0.56	1.84	42	2.53	58
C&I	4.44	23	0.57	2.19	49	2.25	51
C&D	10.61	55	1.35	8.64	81	1.96	19
Total	19.41	100	2.48	12.67	65	6.74	35

(Source data NSW EPA, 2019b)

Figure 4.9 – Waste generation, diversion and disposal by waste stream in NSW (2015-16 to 2017-18)



(Source: NSW EPA, 2019b)

The major component of MSW is domestic household waste which is collected by councils or their representative contractors through kerbside bin collections, drop off and clean up services. Half of the domestic waste collected in NSW is within the SMA, 30 of the 128 NSW LGAs and approximately 4.5 million (58%) of NSW 7.7 million population, refer to Table 4.2.

Table 4.2 – Waste statistics by stream for the SMA in 2016/17

	NSW	SMA	SMA %	NSW (Mt)	T/p	SMA (Mt)	T/p	SMA %	Recycled (Mt)	SMA %
Population	7,725,840	4,474,485	58							
households	2,996,611	1,611,156	54							
Residuals				2.1	0.275	1.13	0.252	54	0.25	22
Organics				0.7	0.090	0.31	0.069	44	0.30	98
Recyclables				0.8	0.104	0.40	0.089	50	0.35	89
Total				3.6	0.469	1.83	0.410	51	0.95	50

(Source data WARR 2016-17) [13]

[13] These figures are less than those reported in NSW EPA (2019a)

Whilst separated organics (i.e. the green lid garden organics bins) and recyclables (the yellow lid bins) have a high rate of recycling, the residuals (red lid bin) have a very low recycling rate in the SMA, only 22%. This makes it difficult to achieve the federal level target of halving food waste by 2030 (CoA, 2017) and more recent national (CoA, 2018; 2019) and NSW state level (NSW DPIE, 2021a) strategies that target separation and management of organics.

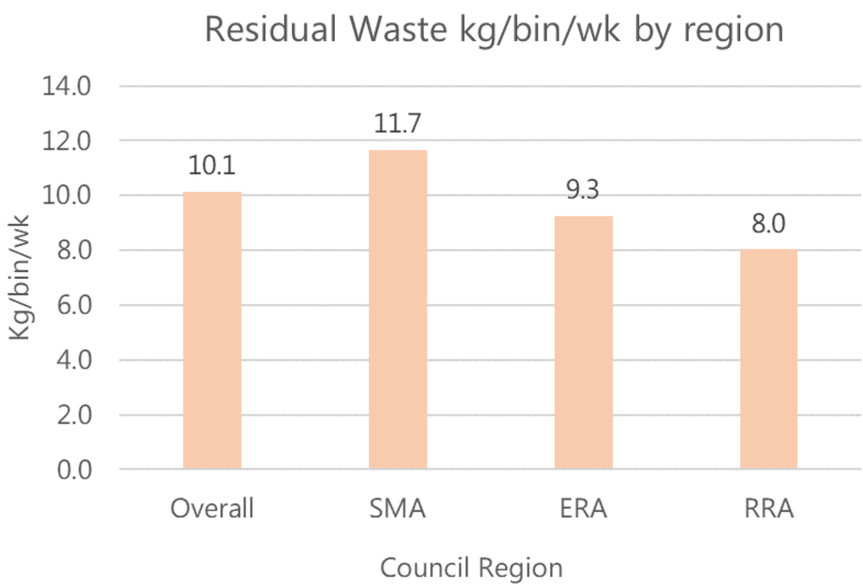
The residuals bin, especially in the Sydney context, is acknowledged as a key waste stream to focus on with respect to achieving targets and improving waste management practices (NSW EPA, 2019b).

4.3.3 SYDNEY RESIDENTIAL WASTE MANAGEMENT FIGURES

A recent NSW EPA commissioned report (Rawtec, 2020), analysed over 13,000 NSW household audits (80% SDs and 17% MUDs) from 2011 to 2019. Most of the audits were conducted between 2014 to 2019, 92%. As shown in Figure 4.10, the SMA households have the highest residual waste, nearly 12 kg/household/week. These figures however need to be used with caution as:

- the audits did not consider the presentation rate of bins or seasonality
- there is an unrepresentative split between SDs and MUDs in the sample
- the audits have been grouped over a long period, which include interventions, that may affect results
- the ERA and RRA have a higher rate of FOGO which would likely remove some organics from residual bins, refer to Figure 1.6 for an indication of high FOGO service provision in regional areas.

Figure 4.10 – Average residual waste generation by levy area



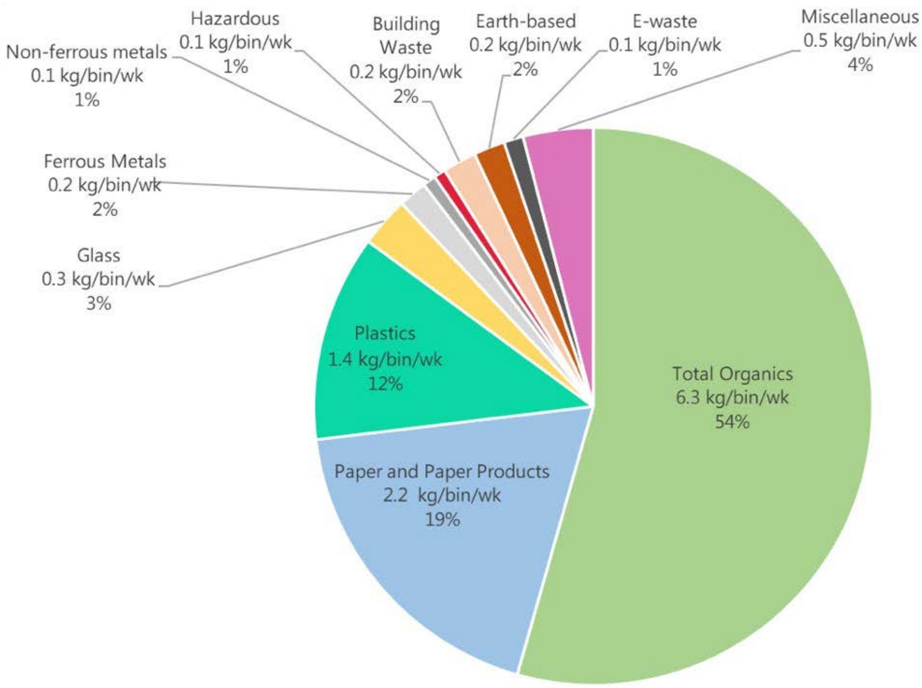
(Source: Rawtec, 2020. Reproduced with permission of author)

The Rawtec (2020) report estimated how some of these factors (i.e. presentation rate of the bins at the kerb) affect these figures when taken into consideration:

- Overall = 8.8 kg/household/week
- SMA = 9.6 kg/household/week
- ERA = 8.3 kg/household/week
- RRA = 7.5 kg/household/week

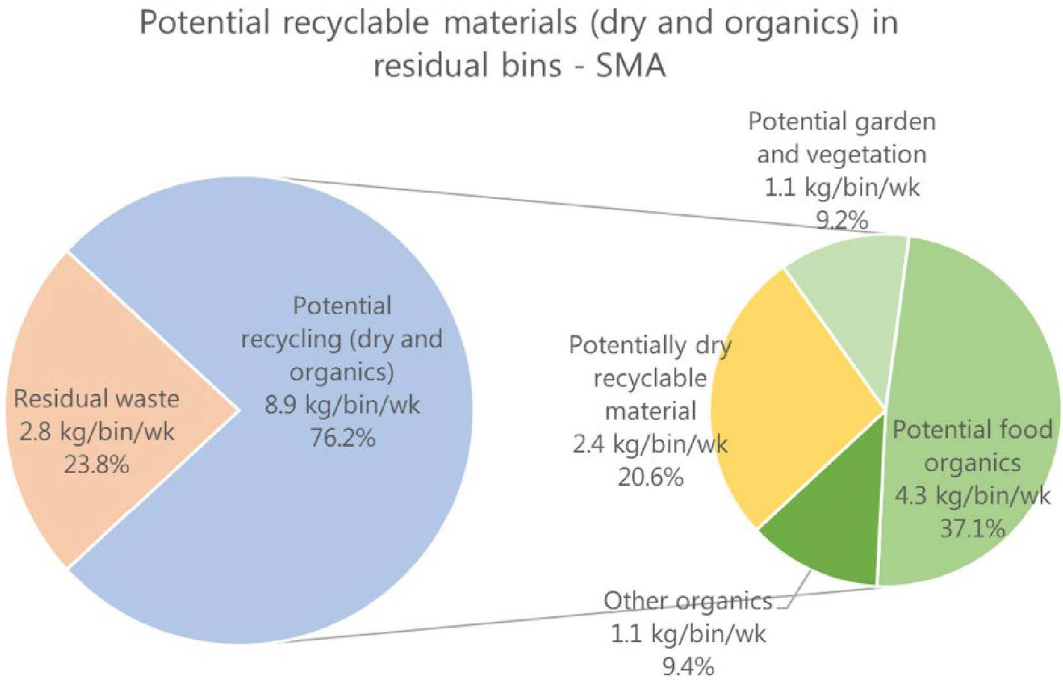
Figure 4.11 indicates the high proportion of organic waste in the SMA residual bins based on analysis of audits across 31 SMA councils in 2019. Figure 4.12 indicates an assessment of the significant potential for recycling within those bins, with the majority of organics still passing to landfill. Again these audits will be affected by various factors such as presentation rates, interventions and seasonality.

Figure 4.11 – Composition of SMA residual bins (2019)



(Source: Rawtec, 2020. Reproduced with permission of author)

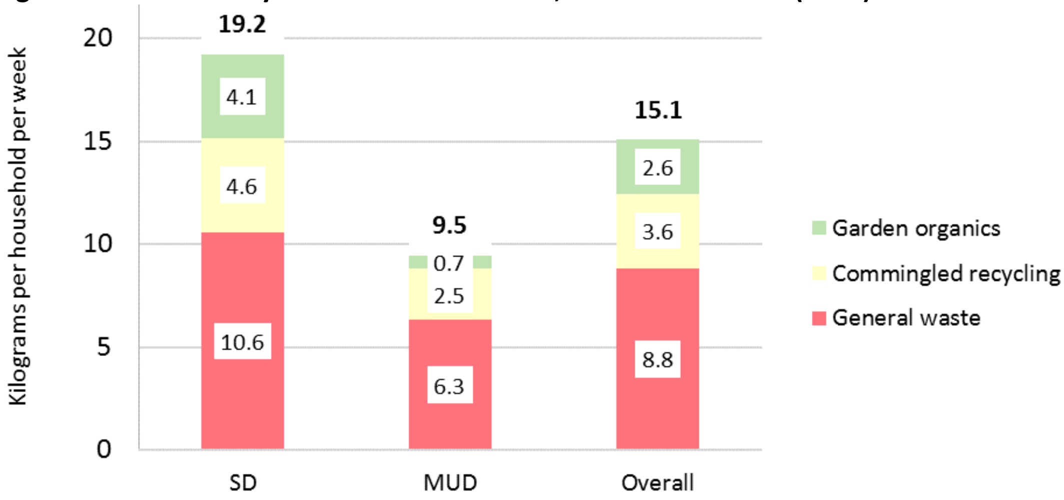
Figure 4.12 – Potential recyclable materials in SMA residual bins (2019)



(Source: Rawtec, 2020. Reproduced with permission of author)

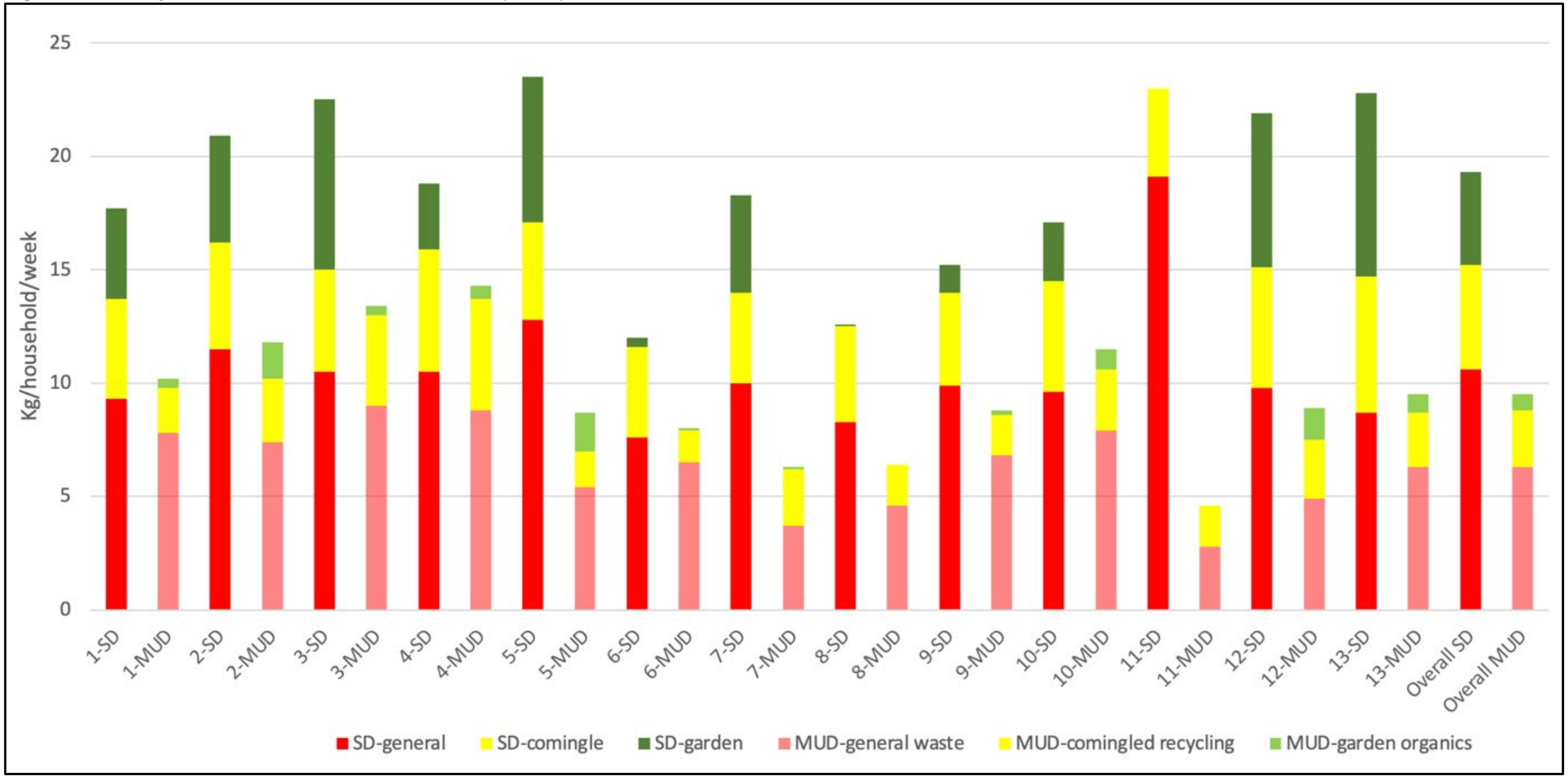
Figure 4.13 and Figure 4.14, provide a more detailed snapshot of a subset of the audits conducted in 2019 for the SSROC area, with a population of just under 2 million in 2016-17, 44% of the SMA population. Figure 4.14 shows the significant variation in waste generated between each council and between SDs and MUDs for 13 of the councils audited, (APC, 2019a). As can be seen, in general, MUDs have very little garden organics compared to SDs and often significantly less in the residual bins.

Figure 4.13 – Summary of SSROC audits for SD, MUDs and overall (2019)



(Source: APC, 2019a. Reproduced with permission of author)

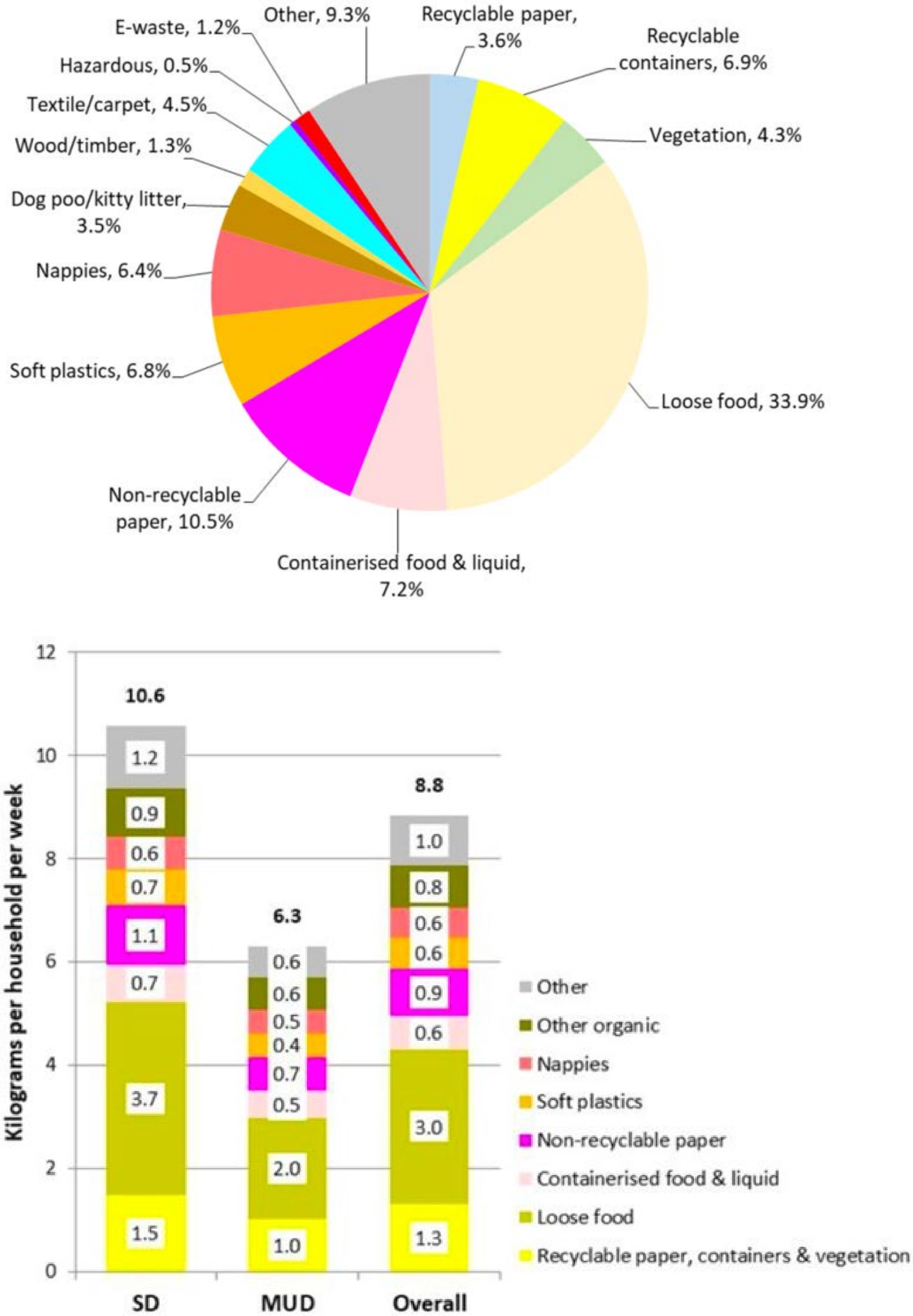
Figure 4.14 – By individual de-identified council (2019)



(Source data APC, 2019a)

Drilling down further, Figure 4.15 indicates the types of materials within the residual waste of the group of 13 councils. The largest stream is food waste but with a marked difference between SDs and MUDs.

Figure 4.15 – Types of materials within residual bins audited for SSROC (2019)



(Source: APC, 2019a. Reproduced with permission of author)

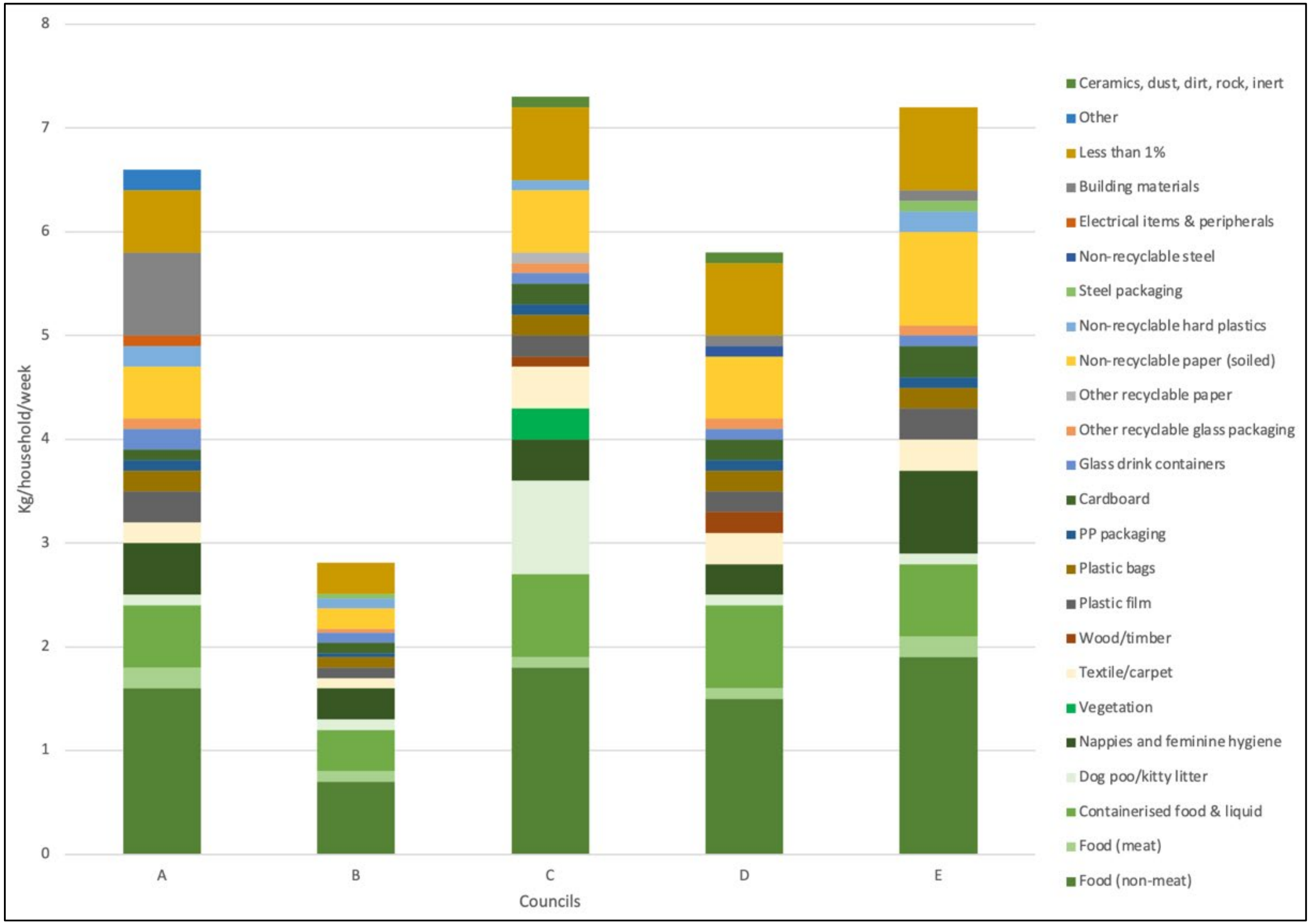
As identified in Section 4.2 the definitions used when conducting audits under the NSW EPA guidelines (DECCW, 2008) are:

- Single dwelling – SD - single, semi-detached, row/terrace or townhouse
- Multi unit dwelling – MUD - flats/units up to three storeys
- Highrise – HR - More than three storeys.

These definitions do not easily align with definitions used by other authorities such as ABS, ID profile or the GSC where information can be obtained publicly, yet again causing difficulty/ambiguity when using data and interpreting reports.

The audits excluded HR dwellings (i.e. buildings of more than 3 storeys) until 2019, as it was thought that such large buildings would skew the results for the MUDs (APC, 2019a). In 2019 a group of nine new and former councils in the SSROC conducted an additional HR audit, in tandem with their usual SD/MUD audits, to investigate the waste generation in this specific growing residential subsector. An available subset of the results of these HR audits are shown in Figure 4.16 for five deidentified councils. The individual non-public HR audit reports show marked variation between individual high rise buildings. However, interestingly, comparing Figure 4.15 and 4.16, the food and containerised food and liquid component in the over 3 storey MUDs (Figure 4.16), for four of the five councils audited, is similar to the 3 or less storey MUDs shown in Figure 4.15. That is, around 2.5 kg/household/week and again significantly less than the SDs. Dog poo/kitty litter and nappies/feminine hygiene, which are rich in organics, are also interestingly significant. Except for Council C in Figure 4.16, vegetation is virtually non-existent compared to MUDs in Figure 4.15.

Figure 4.16 – Results of High Rise audits for a selection of SSROC councils (2019)



(Source data APC, 2019b; 2019c; 2019d; 2019e; 2019f)

The audits, whilst having some limitations, help to outline the differences between the quantity of UOW materials generated between different buildings types and different councils and ultimately how this needs to be considered when:

- forecasting organics, as the proportions of different types of homes change over the coming years
- developing solutions for those different types of dwellings with markedly different characteristics and resource and waste generation intensity

Much of the focus on understanding waste in NSW to date has been at the household level, with councils providing input to the NSW EPA WARR reports on an annual basis[14], the audits of SDs and MUDs by most councils in levy areas and now HR audits by some metro councils. There have also been many other NSW EPA based and individual council based public and non-public investigations on anything from food organics and garden organics contamination issues to evaluations of pilot FOGO programs to assess the potential of full scale program roll out. To aid in waste sector knowledge sharing such research and reports should be brought together for practitioners to improve accessibility, minimise duplication of research and investigations and aid in more detailed planning.

4.3.4 NSW/SYDNEY C&I FIGURES

Due in part to the more dispersed nature of C&I waste management, that is, most councils in the SMA do not provide services to C&I customers, rather businesses need to arrange their own waste management services, there is limited publicly available data for the C&I sector. This provides a significant impediment in garnering the broader waste management picture for the SMA, particularly large streams such as organics which now have specific targets and individual sectors and sub-sectors, such as accommodation, manufacturing or retail, that might be producing such waste to target for interventions.

The NSW EPA has undertaken several studies in an attempt to establish estimates of C&I waste and individual streams within it to help review progress towards policy targets but these estimates have been somewhat ad hoc and the timing between audits/analysis and publication often delayed. Key reports currently publicly available are now very dated and include for example:

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[14] NSW EPA Waste data surveys/Local council waste and resource recovery data available from https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/warr-strategy/policy-makers/surveys

- 2019 - NSW Waste Avoidance and Resource Recovery Progress Report 2017-18 (NSW EPA, 2019a)
- 2017 - NSW Waste Avoidance and Resource Recovery Strategy Progress Report 2014-15 (NSW EPA, 2017)
- 2015 - Disposal-based audit – Commercial and industrial waste stream in the regulated areas of NSW (providing temporal trend data for the SMA in 2003, 2008 and 2014 based on limited audits at landfill and transfer station sites) (NSW EPA, 2015b)
- 2015 - Pilot generator site-based audit – Commercial and industrial waste stream in the MLA of NSW (providing data collected in 2014 on limited audits based at C&I premises generating waste) (NSW EPA, 2015a)
- 2010 - Disposal based survey of the commercial and industrial waste stream in Sydney (for data 2008) (DECCW, 2010)

From this data, in 2014-15 (NSW EPA, 2017):

- 16.6 Mt of waste was generated (including SMA, ERA, RRA and the Rest of the State)
- 6.2 Mt was disposed and
- 10.4 Mt was recycled

Of the NSW waste generated:

- 10.2 Mt (61%) was in the SMA
- 3 Mt (30%) of that SMA waste was attributable to C&I

Also for waste generated in NSW:

- 4.9 Mt (30%) was C&I
- 0.32 Mt (6%) of C&I was food waste
- 0.48 Mt (10%) of C&I was garden organics
- 0.15 Mt (3%) of C&I was classified as other organics

Refer to Table 4.3 for details

Table 4.3 – Waste and organics generated, disposed and recycled based on 2014-15 data

	Total Created	Disposed	Recycled	%
NSW Total Waste	16,558,000	6,154,000	10,404,000	
MSW	5,422,000	2,269,000	3,154,000	33% of NSW total waste
C&I	4,946,000	2,073,000	2,872,000	30% of NSW total waste
C&D	6,190,000	1,811,000	4,378,000	37% of NSW total waste
SMA waste total	10,171,000	3,557,000	6,614,000	61% of NSW total
SMA MSW	2,988,000	1,250,000	1,738,000	
SMA C&I	2,992,000	1,162,000	1,830,000	60% of NSW C&I 30% of SMA total
SMA C&D	4,191,000	1,145,000	3,045,000	
Food waste total	1,229,000	922,500	306,500	7% of NSW total
MSW food waste	912,000	724,000	188,000	17% of total MSW
C&I food waste	317,000	198,500	118,500	6% of NSW C&I 26% of food waste total
Garden organics total	1,755,000	585,500	1,169,500	11% of NSW total
MSW garden organics	1,070,000	342,500	727,500	
C&I garden organics	484,500	119,500	365,000	10% of NSW C&I 28% of garden organics total
C&D garden organics	200,500	123,500	77,000	
Other organics total	911,500	157,000	754,500	
MSW other organics	757,000	168,000	589,000	
C&I other organics	147,500	-18,000	165,500	
C&D other organics	7,000	7,000		

(Source data NSW EPA, 2017)

Using this 2014-15 overview (NSW EPA, 2017) and looking more deeply using the latest publicly available C&I data from 2013-14 (NSW EPA, 2015b), nearly a decade ago:

- 1.8 Mt of C&I waste was sent to landfill from the regulated areas (SMA, ERA, RRA) and of that
- 1.4 Mt (80%) from the SMA

Looking specifically at the material disposed to landfill from SMA, ERA, RRA (NSW EPA, 2015b, p.23):

- 68% of C&I waste taken to disposal sites arrived in mixed loads with the remaining 32% in single loads (categorised as those containing 90% of the same material category)

Figure 4.17 indicates (a) the general content of C&I waste reaching landfill disposal sites, predominantly garbage bags, (b) the content specifically within garbage bags, noting the majority is associated with food waste and some garden organics and (c) the composition of C&I waste when garbage bags have been redistributed.

The redistributed figures in (c) show food waste and garden organics represented nearly 15% of the material sent to landfill. Overall half of the material sent to landfill was considered biodegradable organic material in some form such as wood, paper, cardboard, food waste, textiles, vegetation and nappies. All of these materials contributing to some form of biodegradation in landfills and associated potential GHG, leachate and odour impacts.

The data also indicated that estimated SMA C&I disposed to landfill in 2013-14 (NSW EPA, 2015b) was:

- 127.6 Kt (9%) food waste and
- 74.2 Kt (5.2%) garden organics

Figure 4.18 digs a little deeper showing (a) which industry sectors food waste appears to be concentrated in when disposing to landfill and (b) which industries dispose a high proportion of garbage bags that contain considerable quantities of food waste. This mix of industries is a useful place to investigate food waste as they are likely producing some of the highest quantities of food waste.

There were nearly half a million registered businesses in the GSC area in 2017. Of the industry sectors in Figure 4.18 that can be identified (i.e. the categories of shopping centres and mixed small businesses are not shown in public records) there were over 65,000 (.id, n.d):

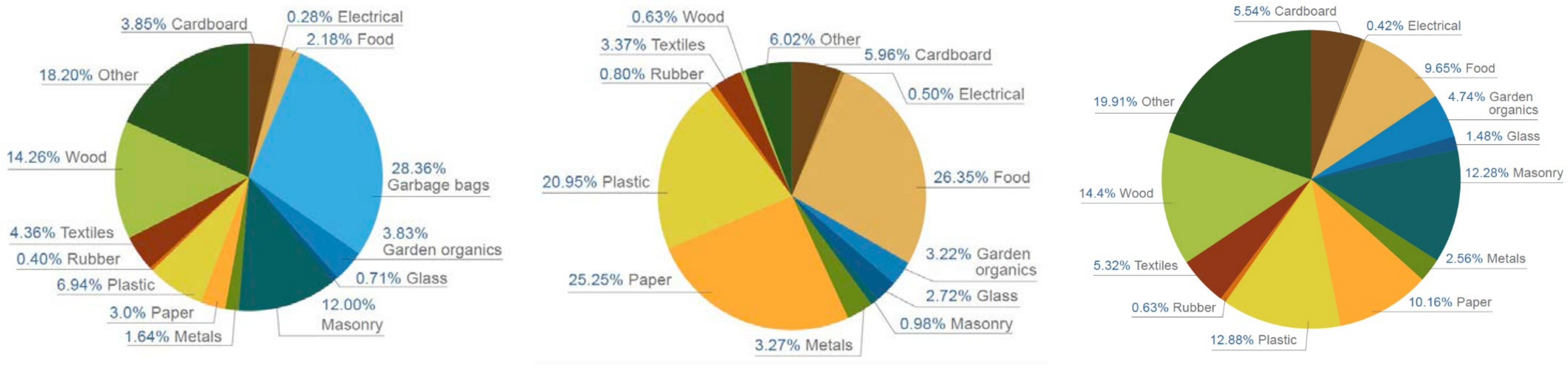
- Accommodation and food services – 19,481
- Manufacturing – 17,021
- Retail – 28,802

These sectors have continued to grow in subsequent years.

Due to both growth in the SMA and interventions since 2013/14 these figures can only provide an indication for the C&I food waste and garden organics component of organics generated and disposed to landfill. Other studies have attempted to establish overviews of C&I and in some cases organics including food waste (PWC & SIP, 2019a; Wesley, 2020). However, they have similarly had to rely predominantly on the dated publicly available NSW EPA data and in some cases NSW EPA non published data where available. New reports are providing more insights into specific streams such as food waste but at the National level (Arcadis, 2019; FIAL, 2021). To enable improved management of organics, especially in the C&I sector, more up to date and improved data collection, analysis and reporting is needed.

Figure 4.17 – Content of C&I waste disposed based on 2013-14 audits

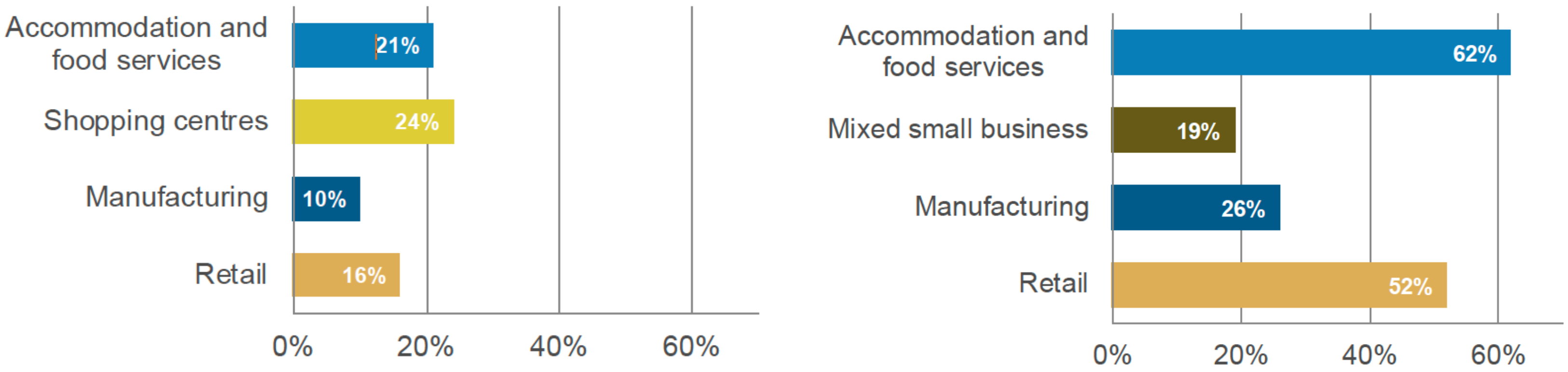
(a) General content (b) Content of garbage bags (c) Composition of C&I including content of bags



(Source: NSW EPA, 2015b)

Figure 4.18 – C& I disposal by key sectors based on 2013-14 audits

(a) Main sectors contributing food waste (b) Main sectors contributing garbage bags



(Source: NSW EPA, 2015b)

4.3.5 INTERVENTIONS

As outlined in Section 1.2.4, the NSW EPA managed the AUD 802 million Waste Less Recycle More (WLRM) program from 2006 to 2021/2022. This included the AUD 105.5 million Organics Infrastructure Fund, which aimed to boost food waste and garden organics recycling and reduce organics sent to landfill. The programs included:

- new or enhanced kerbside collection for food waste and garden organics
- new and enhanced infrastructure and on-site processing for organic waste
- programs to raise awareness of food waste and avoidance (households and businesses) to reduce the amount sent to landfill
- projects that develop new markets or expand existing markets for recycled organics (Turner et al., 2017)

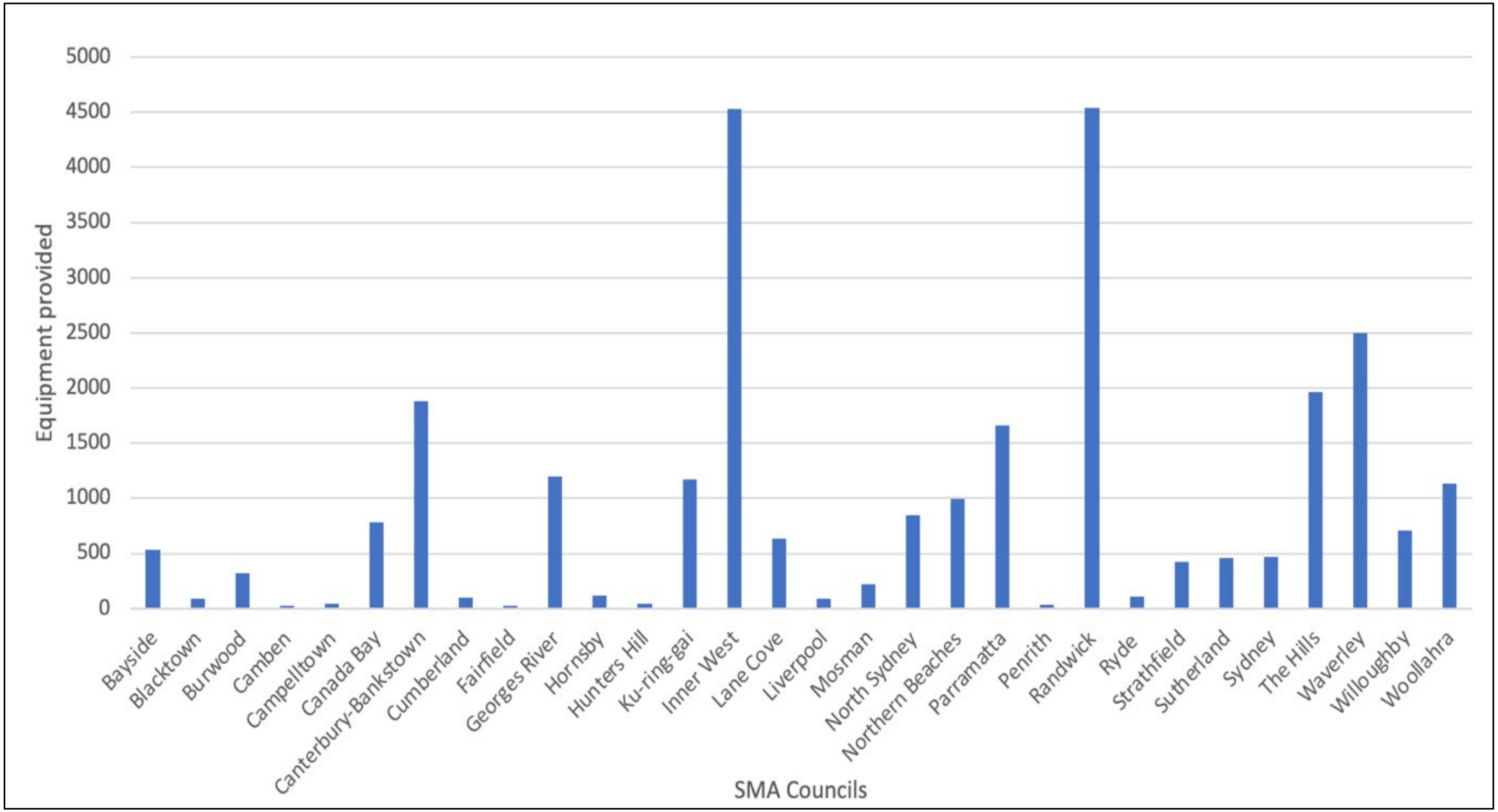
Key government supported activities/interventions have included for example:

- **Love Food Hate Waste (LFHW) at Home** – A program to help households raise awareness about their food waste, plan meals, shop with a list, consider portion size, store food correctly and cook with leftovers. Tips, tricks and resources were provided through NSW EPA websites (NSW EPA, n.d.-e).
- **LFHW at Work** – This included the Your Business is Food program to help food related businesses manage stock, store food correctly, design menus, minimise plate waste and upskill staff through a tool kit and web resources (NSW EPA, n.d.-f)
- **LFHW Grants** - Grants to support eligible organisations to deliver projects that help households or businesses to reduce the quantity of edible food wasted through education (NSW EPA, n.d.-g).
- **WLRM Organics Infrastructure (large and small) Program** – The program funded infrastructure and equipment to reduce food and garden organics waste going to landfill and subsequently supported organisations impacted by the EPA revoking the mixed waste organics outputs orders and exemptions (refer to Box 1). Grants funded infrastructure such as onsite or pre-processing equipment, food donation infrastructure, transfer stations and equipment supporting new markets (NSW, EPA, n.d.-h)
- **Bin Trim** – The program set up in 2014 as part of the NSW EPA WLRM program focused on small and medium sized businesses (Johnston, 2019). With over 38,000 participating businesses across NSW the program aimed to identify actions businesses can take to cut waste, recycle more and boost profits. The program which focused on

both avoidance and recycling offered free or reduced cost waste and recycling assessments by a qualified assessor together with advice, a personalised action plan and access to potential rebate funding of between $1k to $50k to assist with the cost of recycling equipment. An online tool was also available as well as documented case studies.

- **Compost Revolution** – A program that started in 2010 as a joint workshop-based education initiative in Sydney between three neighbouring councils, through NSW state government funding, is now a national program which has assisted over 85,000 households take part in composting workshops and/or buy composting equipment often subsidised by individual local councils (Compost Revolution, n.d.). Figure 4.19 provides a snapshot of household transactions purchasing equipment through Compost Revolution from composters to worm farms, in the SMA region, by council, between 2014/15 and 2019/20. Over 25,000 household transactions were conducted during the period, with the Inner West and Randwick councils being a significant proportion. Randwick council being one of the three original councils initiating the program and both Randwick and the Inner West councils being particularly progressive in terms of food waste and home composting initiatives for over a decade (refer to Appendix E), helping to explain their high uptake.

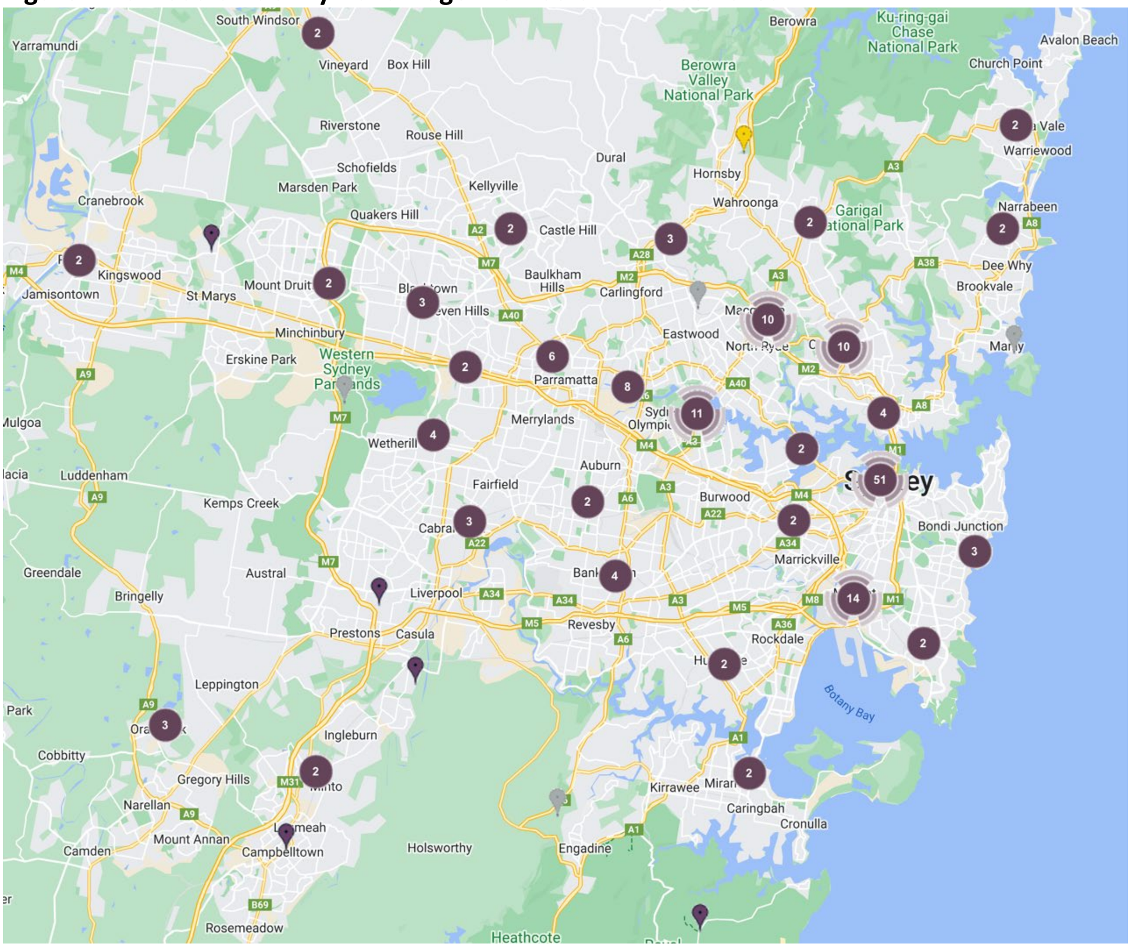
Figure 4.19 – Count of household transactions of composting equipment purchased through Compost Revolution (2014/15 to 2019/20).



(Source data Compost Revolution, n.d.)

- **Sustainability Advantage** – A NSW government initiative focused on medium and large scale organisations. Available for over a decade the program has provided practical assistance and tools as well as capacity building to enable businesses to become more competitive and sustainable. Over 800 organisations have participated in the program. Members in the GSC area are shown in Figure 4.20 and cover a wide spectrum of sectors from aged care and food and beverages to hospitality and retail.

Figure 4.20 – Sustainability Advantage members in the GSC area



(Source data NSW DPE, n.d.)

Many of these programs have been rebranded and will continue to be provided to support the targets of the new 20 year waste management strategy (NSW DPIE, 2021a).

In addition, significant food waste savings have been made over the last decade in non-residential/C&I businesses through avoidance/treatment activities such as:

- ***Food Rescue*** – Oz Harvest – Australia's largest food rescue organisation. In Sydney in 2019 alone Oz Harvest rescued 2.8 kT of food and provided 8.4 million meals by assisting 325 charities with the help of 1,244 donors (Oz Harvest, 2019).
- ***Dehydrators*** – Systems such as Closed Loop and Hungry Giant have been gaining traction in Sydney for several years as a way to remove moisture from food waste on-site to produce a dry, odourless output that can then be transported for further treatment and use as a soil conditioner. By the end of 2017 alone there were already over 50 Hungry Giant dehydrators in Sydney in locations such as Darling Quarter, the State Theatre and Hurstville Central Shopping Centre (WSROC, n.d.).
- ***Food waste maceration*** – Systems such as Pulpmaster, which was established in 2004 in Sydney and is now a Nationwide company that services hundreds of food preparation businesses, macerates food waste and hygienically contains it for regular transfer to composting and AD processing (Pulpmaster, n.d.).

The programs and interventions above are just a selection, many supported in some way by state and local governments. There are a growing number of additional smaller scale socio-technical interventions being implemented across the city. These programs and interventions, by design, aim to reduce the volume of food waste and broader UOW passing to landfill. Such interventions will affect current quantities and projected forecasts of UOW. However, there is currently little collective knowledge of these systems or their locations. Registering and/or collation of such data could assist in more accurate forecasting in the future and a better understanding of potential savings in the residential and non-residential C&I sectors going forward.

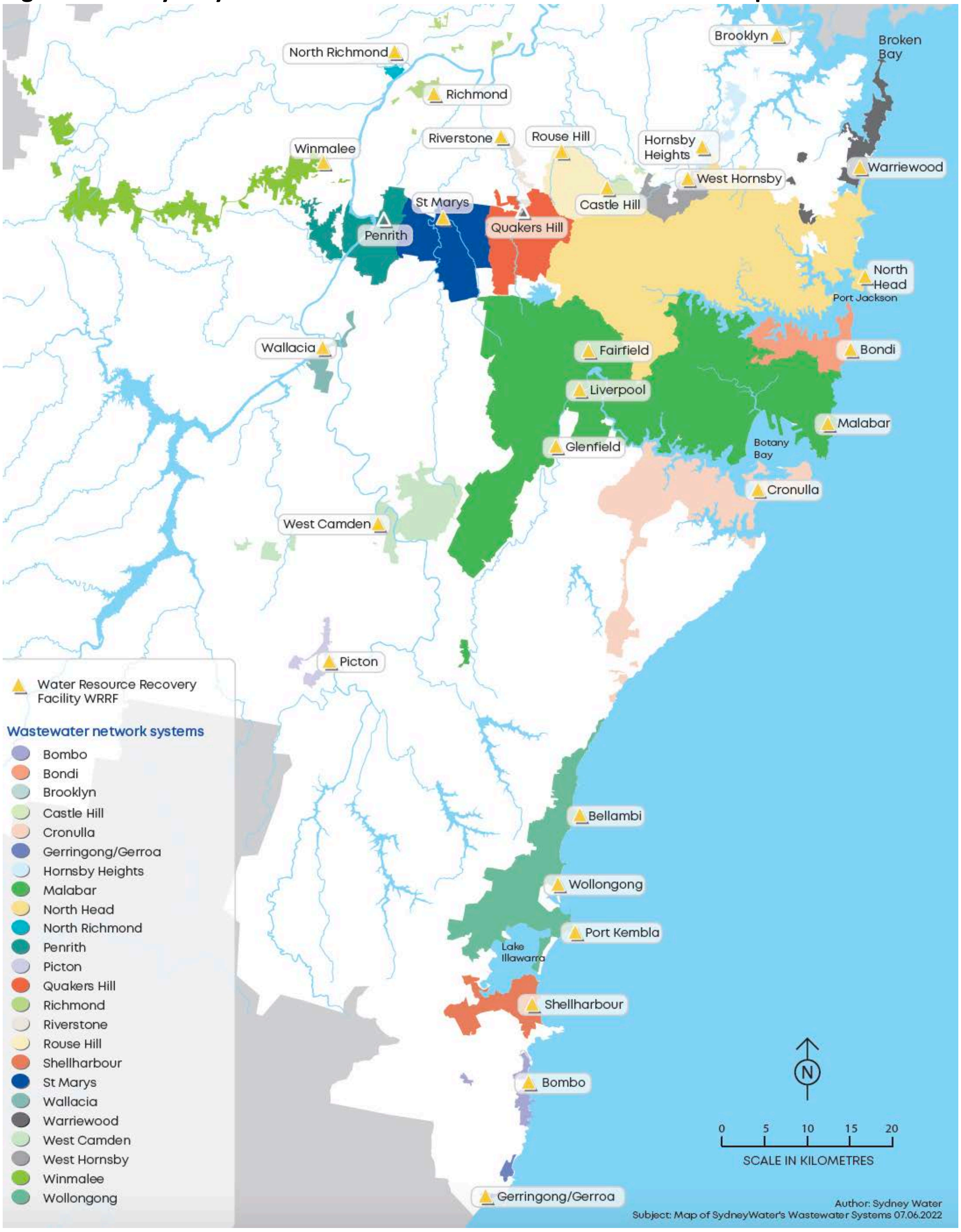
4.4 OTHER ORGANICS

Broader UOW produced and managed in dense urban environments include wastewater and associated biosolids as well as fats oils and grease from non-residential grease traps and used cooking oil which is generated in both the residential and non-residential sectors.

4.4.1 WASTEWATER & BIOSOLIDS

Sydney Water is the largest water/wastewater utility in Australia. As well as providing around 600 GL/a of water to the population of greater Sydney (a similar area to the GSC area but extending south past Wollongong), they remove approximately 465 GL/a of wastewater from around 2 million customers and provide 43 GL/a of recycled water (Woods, 2019). Wastewater is treated through more than 20 wastewater treatment plants. The majority of wastewater is treated to primary level and discharged to deep ocean outfalls via Bondi, Malabar and North Head (>70%) (Sydney Water, n.d.-a). Figure 4.21 highlights the extent of the wastewater network system and treatment plants including the extension south beyond the GSC boundary. Within the GSC area there are also a number of private utility wastewater and recycled water service providers.

Figure 4.21 – Sydney Water wastewater network area and treatment plants



(Source: Sydney Water n.d.-a)

Sydney Water produces over 180,000 T/a of wet biosolids each year from its wastewater treatment plants (Coote, 2017). Biosolids management is strictly managed in accordance with NSW EPA policies and guidelines (NSW EPA, n.d.-i). No Sydney Water biosolids pass to landfill. Around 75% of the biosolids are directly applied to agricultural soils via 40 farms across the central west and south west regions of NSW. The materials are used to improve soil in broad-acre farms growing crops such as canola, wheat, oats, barley and pasture. The remaining 25% of biosolids are further processed by, for example, mixing with green waste and composting and used for agriculture, horticulture, mine rehabilitation and gardens and parklands in Sydney (Coote, 2017; Sydney Water, n.d.-b).

Sydney Water currently have more than 15 AD plants at their wastewater treatment facilities. They generate approximately 20% of their own energy needs through renewable resources. The majority is generated through AD, to produce biogas. Sydney Water have been and continue to be involved in multiple research projects investigating the opportunities of utilising various organic feedstocks for AD co-digestion at their facilities to improve energy and climate change outcomes. Benefits include for example, reduced customer bills, increased business productivity and contributions to state carbon emissions and waste reduction targets (Jazbec et al, 2022; Jazbec et al., 2023; Sydney Water n.d-c.; Woods, 2019).

4.4.2 FATS, OILS AND GREASE (FOG)

Fats, oils and grease are produced from food related businesses and the retail food industry, including shopping centres. To protect the wastewater system and treatment plants from blockages such as fatbergs, properties with food related businesses are typically required to have some form of pre-treatment to discharge to the Sydney Water wastewater system. They typically require a discharge licence and need to connect to a grease trap to collect fats, oils and grease before the remaining wastewater discharges to the wastewater network (Sydney Water, n.d.-d). The fats, oils and grease can be collected by any of the nearly 30 Sydney Water approved Wastesafe transporters who take the materials to approved processing and treatment facilities (Sydney Water, n.d.-e). Grease trap waste in Australia is most commonly composted (Pickin et al., 2020). However, the material can also be treated through AD to produce energy (i.e. EarthPower in the middle of Sydney) or applied to land as a soil amendment via soil injection (NSW EPA, n.d.-j).

Grease trap waste is generally not measured. When a license agreement is established with Sydney Water an assessment is made of the type of business, the volume of the grease trap in place and an estimate of the frequency of collection needed. Based on recent Sydney Water data there are over 21,000 grease traps in the GSC area, often multiple traps at one property, with an estimated 20 ML/a of grease from the grease traps extracted.

4.5 SUMMARY OF GAPS & OPPORTUNITIES

In this Section I have provided an overview of Sydney and core characteristics that affect UOW. Whilst at the national level there are now more frequent and up to date reports that give an overview of various UOW streams (Pickin et al., 2020), including food waste (Arcadis 2019; FIAL 2021), there is an acknowledged lack of data [15] as discussed in Section 1.0. Such data gaps obscure a complete picture of UOW generation and cross-sectoral management opportunities in large cities such as Sydney which have highly fragmented UOW management.

A number of specific issues facing Sydney, with respect to UOW management, are raised here, including:

- Inconsistencies and recent changes around boundary definitions between various agencies and sectors involved in planning and the management of UOW systems, which are causing ambiguity and complicating even basic statistics about UOW in the city.
- Significant population growth and urban densification, which varies across the city, and which will have a major impact on urban form, resource use, waste generation and essential services provision.
- Significant growth in MUDs and mixed use/precincts which will affect UOW forecasts. This compounded by inconsistencies in definitions around residential dwelling types between different authorities and collation of audit data which affects its use for analysis.
- Fragmented management of the C&I sector and dated C&I data which makes it difficult to ascertain current UOW generation.
- A lack of collective knowledge of smaller-scale UOW socio-technical systems, despite government supported organics waste management programs and other interventions

[15] "negligible publicly available data on food waste quantities, composition and destinations… where… gaps occur in all sectors of the food supply and consumption chain", this as reported by the first national report on food waste (Arcadis 2019)

having been implemented over the last decade, which limits knowledge on overall UOW generation and opportunities for avoidance.

- Little co-ordinated knowledge on other UOW streams (wastewater, fats, oils and grease from grease traps and used cooking oils) and publicly available data (beyond council managed food and garden organics) that could aid analysis into cross-sectoral opportunities including AD.

Overall there is a need to improve Sydney based UOW data measurement, collation and analysis to assist in improved planning and decision-making. This particularly the case for Sydney considering nearly 20% of all the projected dwellings in Sydney in the year 2036 haven’t been built yet and almost 40% of houses anticipated by the middle of the century. Such a significant increase in new housing stock provides a major opportunity to influence how they are developed now and how the associated essential services are provided.

5 SYDNEY-BASED NESTED CASE STUDIES

Section 4.0 provided an overview of Sydney and examined details and characteristics about the city that affect UOW and its management, from lack of boundary alignment and data collection to population growth and urban densification. Many of the gaps identified also acknowledged in the literature, as discussed in Sections 2.0 and 3.0. In this Section, I go into more detail about Sydney through the use of Sydney-based nested case studies. The case studies were used to help address many of the identified UOW management knowledge gaps. The gaps investigated predominantly focused on (1) the types and quantities of UOW at various scales in Sydney and (2) the range of potential options available at different scales to help manage those materials in specific contexts, especially smaller, local-scale, innovative socio-technical solutions. In this Section I give an overview of the case studies and how they were developed. I then provide details of the collaborators involved, the aims of the studies, the funders motivations and main outputs, which are mostly publicly available to assist in UOW knowledge sharing. I also summarise the methodology for each study, key methods used, overall findings and my specific contributions. The case studies were all developed and conducted before the new NSW 20-year waste strategy was released in mid-2021 (NSW DPIE, 2021a). Each case study provides new insights not previously available and useful to those stakeholders needing to manage UOW and help achieve the new waste management targets. They also demonstrate the use of IRP, systems thinking and sustainability transitions concepts and methods, not previously used in UOW management as further discussed in Part IV.

5.1 OVERVIEW

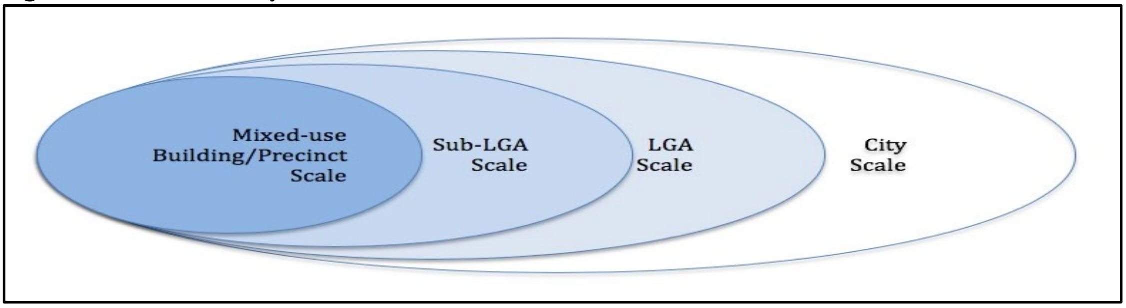
The three Sydney-based nested case studies were all co-developed with Sydney-based industry partners, as is normal for transdisciplinary research. The studies were all conducted by university research teams of between two and four researchers in collaboration with varying industry partners, between early 2017 and the end of 2020. Each case study was used to fill specific UOW knowledge gaps identified by the Sydney-based industry practitioners, funding the research, and the researchers involved in the studies.

The case studies each use multiple IRP concepts and methods, as discussed in Section 3.2, as well as those based in systems thinking and sustainability transitions, discussed in Sections 3.3 and 3.4. Many of the methods used have not previously been applied to UOW at this level of detail and thus help to provide new insights. A summary of the Sydney-based nested case studies is provided here. An IRP meta-analysis of the concepts and methods used is discussed in Part IV in Sections 6.0, 7.0 and 8.0.

The three case studies were purposefully conducted at different scales, as shown in Figure 5.1. Each case study with a leading stakeholder that could take some form of action. The case studies included:

- **Central Park (CP)** – The Central Park Precinct Organics Management Feasibility Study - mixed-use building/precinct scale.
- **Pyrmont-Ultimo Precinct (PUP)** - The Pyrmont-Ultimo Precinct Scale Organics Management Scoping Study - sub-LGA scale.
- **Inner West Council (IWC)** - Organics Revolution: Planning for 2036 and Beyond - LGA scale.

Figure 5.1 – Case study scales examined



The PUP case study was conducted first, in 2017, at the sub-LGA scale. It was born from a network of sustainability practitioners (Smart Locale [16]) located in the PUP area, interested in investigating local sustainability initiatives including food waste management opportunities. As part of the design of the study it generated interest in broader UOW and innovative solutions. This interest resulted in several of those involved in the Smart Locale network collaboratively designing and funding the CP case study in 2017-2018 within the PUP case study geographical boundary. The CP case study investigated organic waste generated in the newly built mixed use building/precinct scale development (One Central Park) and innovative technology to manage UOW on-site. The PUP and CP case studies both subsequently generated interest with waste practitioners when presented to broader groups at various fora. This interest resulted in the IWC case study (2018-2020), which investigated UOW generation and potential innovative

[16] Smart Locale was originally co-ordinated through representatives from the Total Environment Centre (TEC) and involved representatives from organisations such as the TEC, University of Technology Sydney, TAFE, Dynamic4, Flow Systems and Sydney Water. The projects generated through Smart locale have transitioned into multiple local research projects managed under separate initiatives.

solutions from avoidance to centralised treatment at the IWC LGA scale. See Figure 5.2 for case study timing.

Each case study built on the knowledge of the previous study and the methods developed and both deepened and broadened the scope and analysis possible.

Figure 5.2 – Case study scales and timing

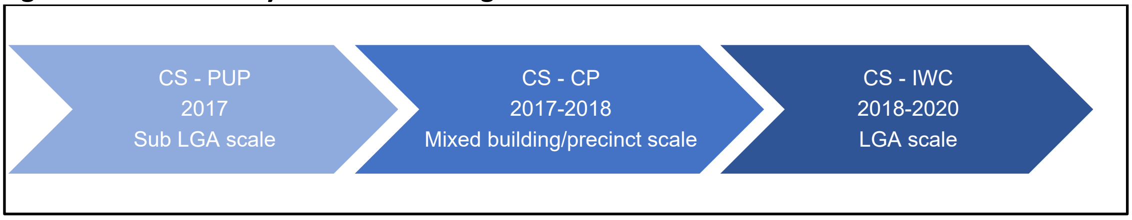


Table 5.1 provides a summary of the aims, funders motivations (i.e. gaps they specifically wished to fill) and outputs from each of the case studies.

Table 5.1 – Summary of case study collaborators, aims, funders motivations and outputs

Case Study	Year	Collaborators	Core aims	Funder Key Motivations	Outputs
CP	2017-2018	Funding - City of Sydney (council) innovation grant - Flow Systems (private utility) In-kind support - JLL (property manager) - Active Research (AD specialist) - Avac (Vacuum system specialist)	• assess, at a high level, the feasibility of innovative technology, specifically on-site AD and vacuum systems, at the building/precinct scale. • investigate the various types, quantities and bioenergy potential of on-site UOW at One Central Park (mixed use building), • specifically investigate One Central Park, within a AUD 2 billion 5 star Green Star development in Sydney, as potential for grant/industry pilot and demonstration site for future precinct developments	• City of Sydney – to assist in exploring whether AD (and vacuum) systems, currently absent in dense urban environments in Australia but with significant potential, are feasible and with the ultimate aim of assisting in funding a pilot/demonstration site if warranted. • Flow Systems – to assess at a high level the feasibility of and potential to install an onsite AD plant in the existing water recycling plant area managed by Flow Systems and to use onsite UOW to generate energy that might be used on site.	Public report (Turner et al., 2017)
PUP	2017	Funding - Sydney Water - NSW EPA Involved – members of Smart Locale Interviews – Sydney Water, NSW EPA, Flow (private utility), technology providers & local council reps	• investigate, at a high level, the volumes/mass of various types of UOW in the PUP area in the heart of Sydney, at the time the highest population density in Australia • investigate innovative UOW management solutions and suite of illustrative options that could potentially manage UOW in the area • garner insights that might be useful for Sydney more broadly and lead to a pilot in the PUP area	• Sydney Water – to gain an understanding of the potential volumes of various organics within a dense urban context to identify potential organics resources they might be able to tap into in the future if they were able to draw on waste industry materials to feed their AD plants across Sydney to assist in Sydney Water energy generation, offset energy costs and contribute to GHG reduction targets. • NSW EPA - interest in scanning solutions implemented across the world that could potentially be applicable in the Sydney context as part of their Organics Infrastructure Funding program to encourage and incentivise organics avoidance and treatment and to assist in achieving the NSW WARR targets	Public report (Turner et al., 2018)

Case Study	Year	Collaborators	Core aims	Funder Key Motivations	Outputs
		Workshop – as above + UTS, SSROC, retail and NSW government representatives			
IWC	2018-2020	Funding - Inner West Council (IWC) Involved – IWC, Sydney Water & NSW EPA (data) Workshop - IWC	• build on the learnings from the previous two case studies (PUP and CP) • map UOW generation at the LGA scale • update and expand the inventory of options available • develop a suite of illustrative UOW options for IWC • go further into the assessment of costs and benefits of UOW options • explore decision-making approaches	• The study was funded by IWC. • Data/in kind support was provided by Sydney Water and additional data provided by the NSW EPA. • IWC – motivation was to identifying broader UOW generation in the LGA and to assist in identifying illustrative potential solutions that might assist the council in achieving aspirational goals of a zero waste community.	Non-public report Jazbec et al., 2020a; 2020b; Public presentation Jazbec et al., 2021)

5.2 MY CONTRIBUTIONS

As identified in Section 5.1 above the case studies were all conducted in research teams and in collaboration with industry practitioners. My specific involvement and contributions for each case study included the following.

5.2.1 CP CASE STUDY

I conducted the study with one other research team member and in collaboration with:

- Flow Systems [17] a private utility managing the water recycling plant on site,
- JLL the commercial/retail property manager for the site
- Active Research an AD specialist
- Avac a vacuum specialist

Each organisation provided data and expert advice.

In the case study I specifically:

- co-designed the project with my co-researcher and the industry co-funder as part of an innovation grant submission to the City of Sydney
- collated disparate sets of data (from measured to estimated) from multiple sources due to the fragmented management of the organics on-site
- conducted the analysis and modelling to gain a holistic systems perspective of the UOW management of the site, potential spectrum of innovative options and associated costs and benefits
- structured and wrote the majority of the case study report as lead author including findings and recommendations

5.2.2 PUP CASE STUDY

I conducted the study with two other research team members, with assistance of a fourth for a limited period. I specifically:

- co-designed the study with one other researcher and the funders, Sydney Water and the NSW EPA
- collated data to assist in the mapping conducted by a research team analyst

[17] Flow Systems is now Altogether a private multi-utility servicing customers in NSW and Queensland (https://altogethergroup.com.au/about/who-we-are/)

- conducted in-depth investigations for four mini case study sites within the PUP study area (i.e. the University of Technology Sydney, TAFE, One Central Park and the Fish Markets) to augment the analysis and mapping data
- conducted the literature review and document analysis of international socio-technical organics solutions to produce a suite of over 35 vignettes
- developed illustrative options mapped against the hot spot maps produced by the research team analyst
- was involved in all stakeholder interviews
- co-designed, hosted and presented the study research at the stakeholder workshop at the end of the study and collated and synthesised the resulting workshop discussions
- partially analysed the interviews and workshop outcomes to specifically draw out themes relevant to drivers/motivations for innovative UOW management solutions, potential unintended impacts from new solutions, and the kinds of criteria/features needed in decision-making in UOW management based on stakeholders perceptions
- structured and wrote the majority of the study report as lead author including findings and recommendations

5.2.3 IWC CASE STUDY

I conducted this study with three other research team members. I specifically:

- co-designed the project with one other research team member and the funder, IWC
- played a key advisory role in all data collection, analysis and mapping for the team, based on my experience in the previous two case studies and IRP waste and water experience
- conducted the initial stakeholder analysis workshop with IWC staff and synthesised the results
- generated the inventory of options from an international literature/document review
- conducted a preliminary literature review of decision-making approaches
- designed and led the internal IWC options workshop with 15 IWC staff to discuss decision-making and workshop potential illustrative options for the IWC area based on the data analysis and mapping conducted
- analysed and synthesised the workshop findings into a sub-report
- co-designed and helped conduct costs and benefits analysis of the suite of illustrative options for IWC modelled by the research team project manager/analyst

- structured and wrote major sections of the study report and reviewed the entire report as the main co-author

5.3 CASE STUDY SUMMARIES

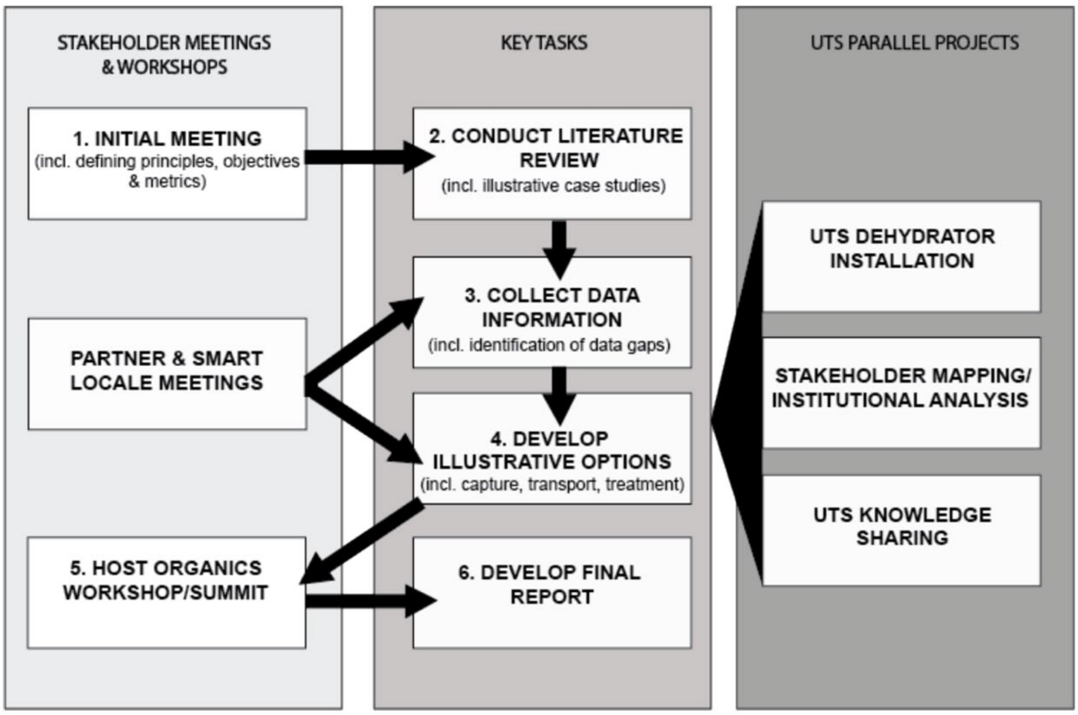
The details of each of the case studies are provided in each of the separate reports provided in the Appendices. The CP and PUP studies are both public reports. The IWC report was intended to be a public report but due to changes in executive staff and direction at the council the report remains confidential and is thus contained within a confidential Appendix. A brief summary of each of the case studies is provided below.

5.3.1 PUP CASE STUDY

5.3.1.1 RESEARCH APPROACH

The PUP case study ,conducted in 2017, was the first case study conducted out of the three nested case studies. The CP and IWC cases studies leveraged off this initial study. An outline of the PUP case study approach is shown in Figure 5.3.

Figure 5.3 – PUP case study research approach



(Source: Turner et al., 2017)

A mixed methods approach was used including:

- Desktop review of national and international literature on innovative systems and practices on the collection, transport, treatment and reuse of organic waste in the residential, commercial and institutional sectors.
- Literature synthesis into vignettes of innovative approaches to UOW management.
- Data collection, material flows analysis and geospatial mapping of organic waste flows within the PUP area.
- Case study analysis of four key sites within the PUP area to gather more detailed data to analyse potential opportunities for innovation.
- Semi-structured interviews with key industry and government stakeholders to identify motivations, enablers and disablers of innovation.
- Options analysis to explore a suite of potential innovative organics options relevant to the PUP context**.**
- A workshop with key stakeholders to share innovative options, seek participant feedback, validate research findings and identify next steps and potential pilots/demonstration sites in the PUP area in the future.
- Report synthesis.

5.3.1.2 KEY NOVEL APPROACHES USED AND KNOWLEDGE GAPS FILLED

Key novel approaches and knowledge gaps filled included:

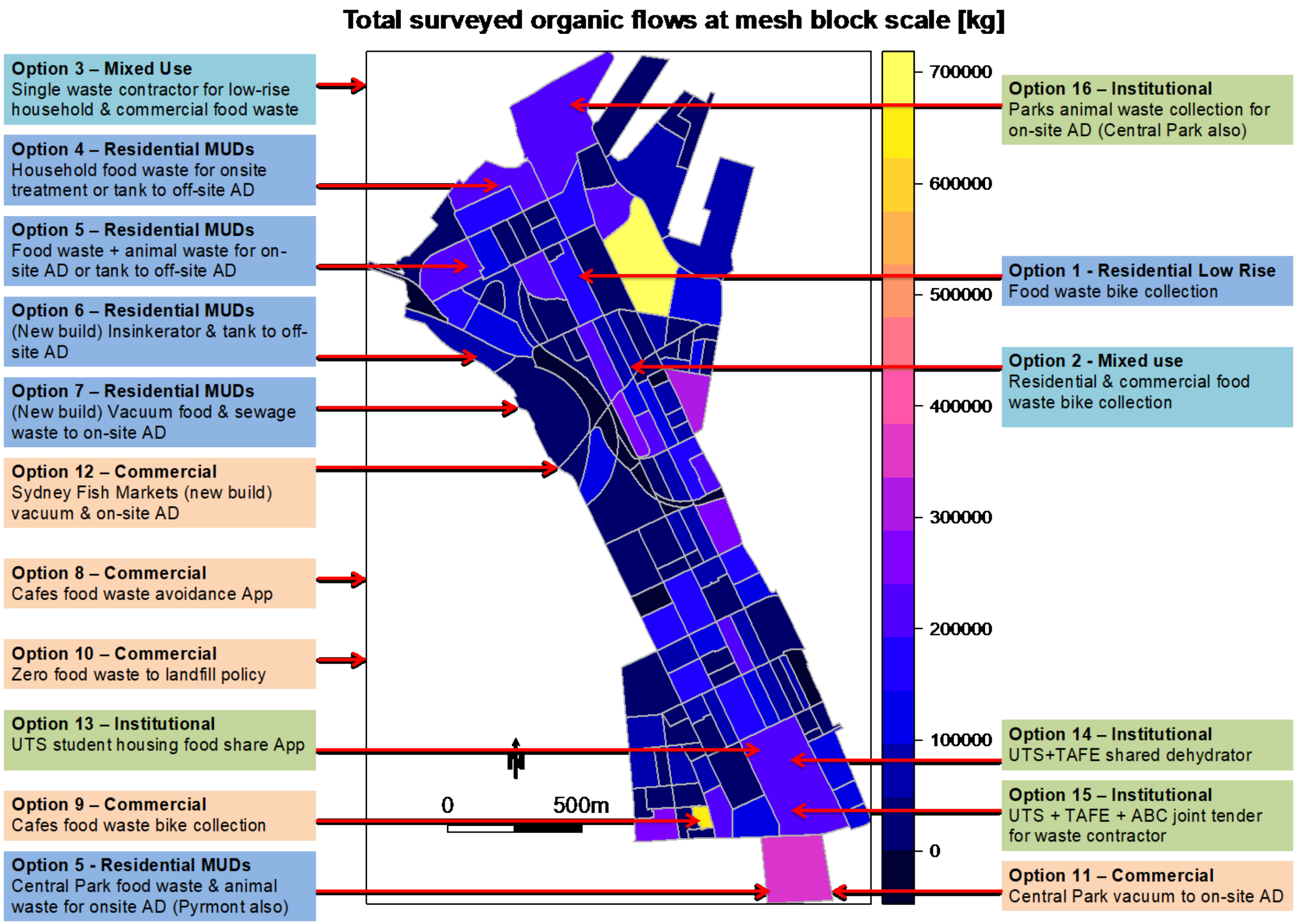
- The study brought together diverse stakeholders (i.e. Sydney Water, NSW EPA, managers of individual sites) at a sub LGA-scale. This enabled the pooling of disparate data sets (i.e. residential food waste, commercial food waste, fats, oils and grease from grease traps, wastewater) for the first time to assist in analysis of UOW with the potential to take action on UOW management at a local sub-LGA scale in Sydney.
- The development of UOW geospatial hotspot analysis and mapping of various UOW streams at a sub-LGA scale for the first time within Sydney to assist in developing methodologies for broader application.
- The collation of a broad selection of international and national innovative UOW management solutions at various scales for NSW EPA knowledge gathering and dissemination. This to assist in incentivising innovative UOW management within NSW and Sydney and help waste practitioners work towards achieving relevant state targets at that time.

5.3.1.3 KEY FINDINGS

The key findings from the case study included:

- There are significant quantities of various UOW in dense urban environments such as the PUP area, at the time the densest area in Australia. Most are not measured but through assessment of various data sets a picture of UOW can begin to emerge, with residential food waste and wastewater biosolids the highest T/a in the area, although commercial food waste is only a partial picture. Waste statistics estimated include; residential food waste –2,940 t/a (council waste audit data), commercial food waste – over 945 t/a (based on over 550 Bin Trim audits provided by the NSW EPA and Central Park), grease from grease trap waste – over 200 t/a (based on 120 grease traps in the PUP are provided by Sydney Water and Central Park), volatile solids from sewage – 7,830 t/a (based on the water usage of over 1,000 properties in the area provided by Sydney Water and assumed sewage discharge factors).
- Geospatial hotspot mapping is a useful method to visualise the various UOW streams, both separately and in combination, as shown in Figure 5.4 and to aid option design, UOW stakeholder engagement and discussions on options opportunities.
- Many and diverse socio-technical options at various scales are being implemented internationally and applicable in dense urban environments such as the PUP area although not used in Australia yet to any great extent despite significant opportunities (refer to Appendix E for examples and references).
- The significant breadth of socio-technical options applicable to PUP, as shown in Figure 5.4, indicate that context matters and that not one size fits all.
- Stakeholders motives for implementing innovative solutions go well beyond the waste hierarchy, often the focus of the NSW EPA, and include other economic/financial, social and environmental motivations not considered by the waste hierarchy.
- Despite a lack of examples within Australia, a rapid assessment of options within a workshop environment including diverse stakeholders indicated options including banning food waste from landfill and embracing local scale AD were highly favourable and that decision-making is highly context and stakeholder dependent.

Figure 5.4 – Geospatial hotspot mapping and visualisation of potential illustrative options



(Source: Turner et al 2017)

Key recommendations included:

- Conduct further data collation, mapping and analysis to provide a more holistic picture of UOW in Sydney with broader stakeholder input and associated data sets (i.e. LGA to city scale).
- Investigate potential options developed as part of the PUP case study, including AD and vacuum systems, to create a hub for sustainable UOW pilots and build on the existing University of Technology food waste decomposer/dehydrator.
- Further investigate and develop a broader suite of options including costs and benefits analysis.
- Assess current decision-making for UOW and develop a framework/tool for councils to assist in selecting options.
- Conduct an annual organics summit and web portal to aid in inspiration on organics management and knowledge transfer.

The recommendations led to:

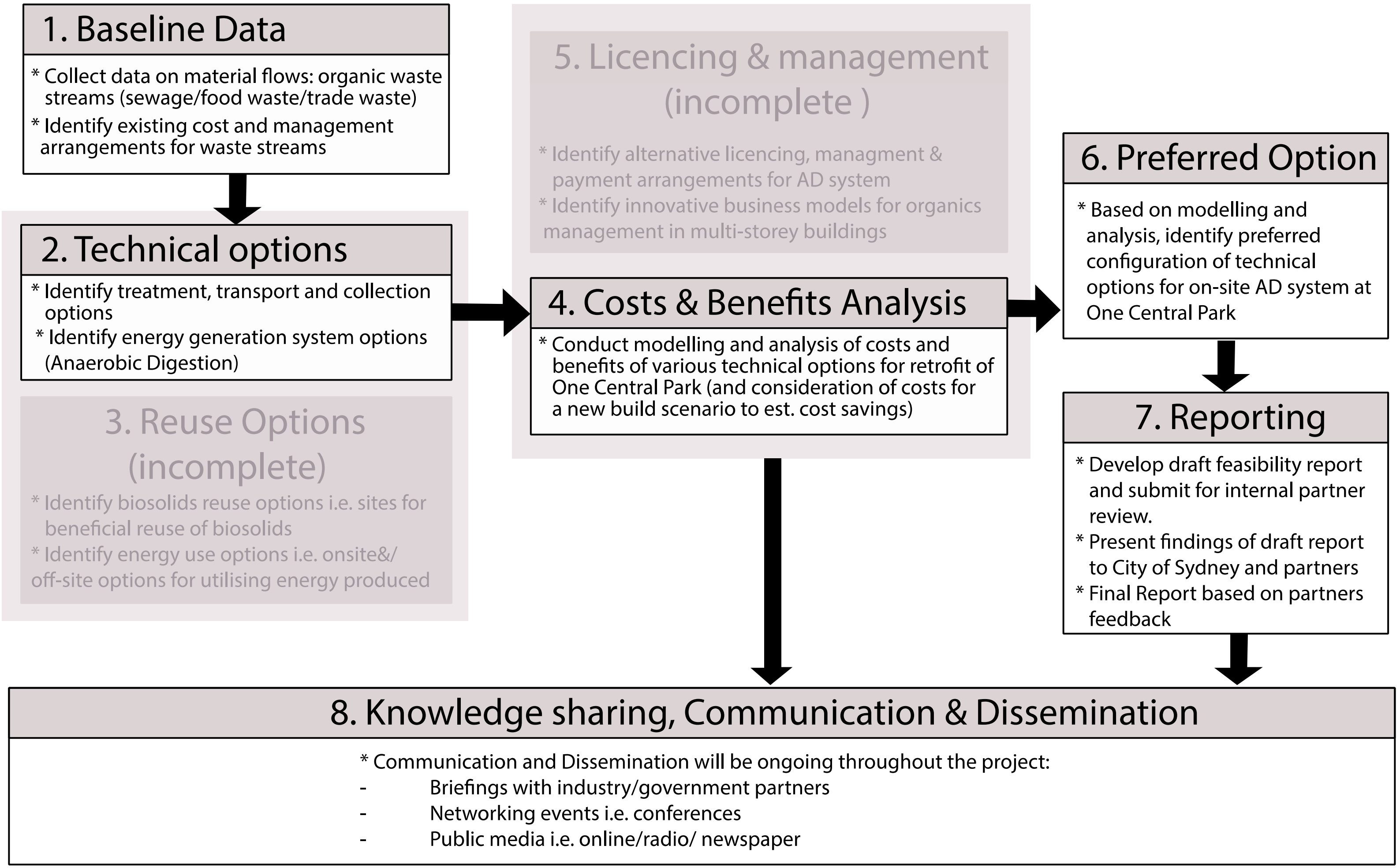
- The CP case study
- IWC case study
- Organix19 Summit
- The UOW IRP framework discussed in Section 9.0

5.3.2 CP CASE STUDY

5.3.2.1 RESEARCH APPROACH

The CP case study was the second case study conducted and was developed as a direct result of the PUP case study investigations and recommendations. Again, a mixed methods approach was used as shown in Figure 5.5, this time however with the focus on one site (One Central Park a new AUD 2 billion development). The study involved data collation, analysis and modelling, options development, as well as high level assessment of costs and benefits. During the research, due to the extensive time necessary to obtain data, some of the research tasks were not completed (i.e. shaded areas) or had to be reduced in terms of scope.

Figure 5.5 – CP case study research approach



(Source: Turner et al., 2018)

5.3.2.2 KEY NOVEL APPROACHES AND KNOWLEDGE GAPS FILLED

Key novel approaches and knowledge gaps filled included:

- Bringing together interested parties for building/precinct scale UOW management investigation with multiple data sets and information (i.e. disparate UOW streams, volumes, management, processing arrangements, costs, benefits) that provide an approach for other building/precinct scale developments.
- Actual measurement of building/precinct food waste and additional data and estimates of various streams to fill major paucity in data on commercial/retail UOW at the building/precinct scale, which is a significant and growing sub-sector in Sydney.
- High level estimation of UOW bioenergy potential, sizing and costs of novel AD and vacuum technology for building/precinct scale developments for the first time in Sydney and Australia to assist in subsequent detailed feasibility analysis and potential for investment in a demonstration site.
- First publicly available UOW visualisation of management arrangements within a building/precinct scale development and destination maps illustrating the significant distances waste is currently needing to travel for treatment and reuse/disposal of the various UOW streams within just one building/precinct scale development.

5.3.2.3 KEY FINDINGS

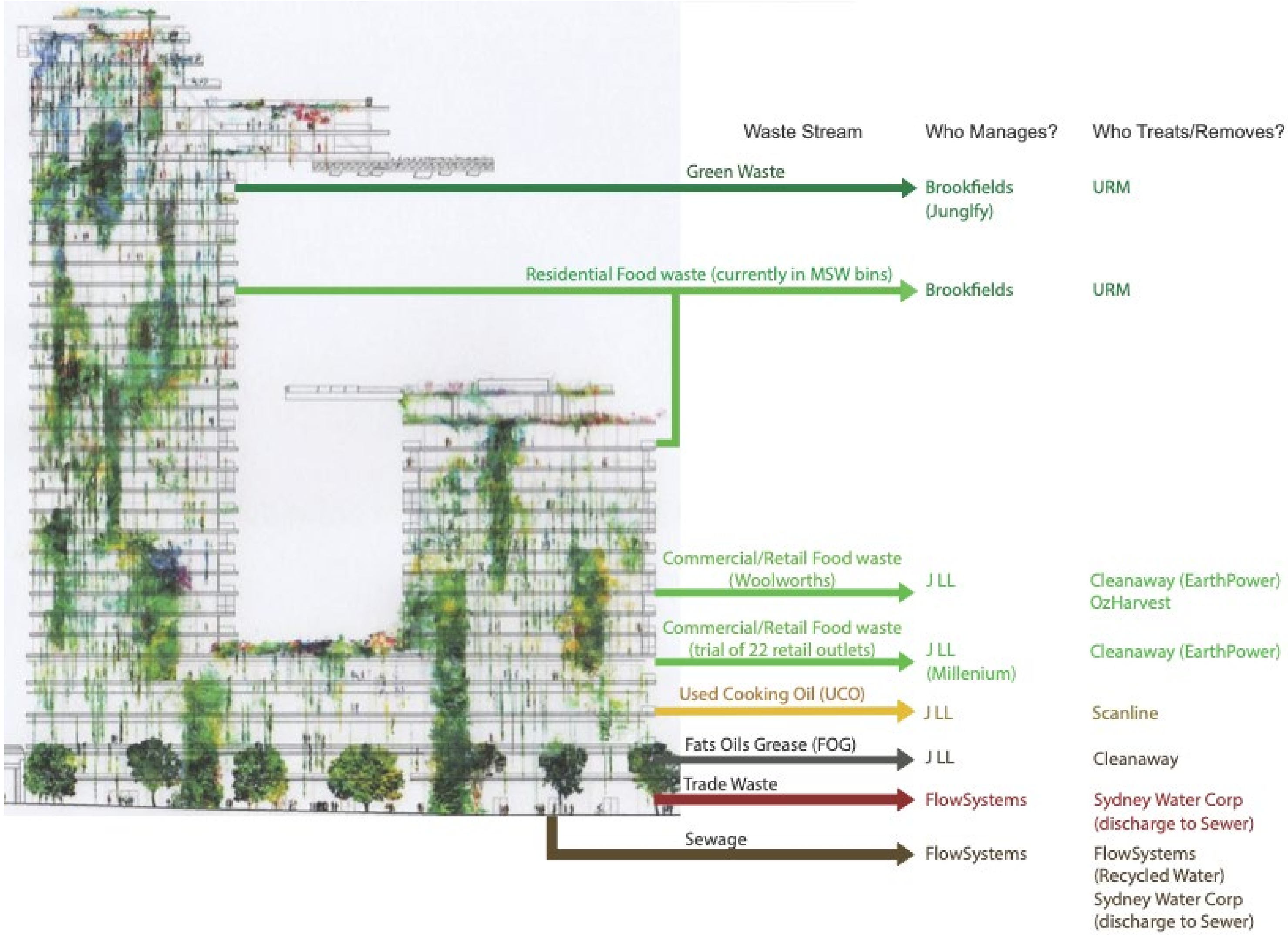
The CP case study provided valuable insights on building/precinct scale developments in Sydney, which will dominate growth in the city in the coming years as discussed in Section 4.0. Full findings are included in the report in Appendix C. Some of the key findings from the case study included:

- Multiple stakeholders are involved in UOW in mixed use building/precinct scale developments such as One Central Park, with the materials taken to multiple sites for treatment and disposal, including 200 km to the south (refer to Figure 5.6 (a) and (b)). This makes it difficult to garner a holistic picture of UOW and how to potentially manage it and contributes to GHG and traffic congestion issues. However, retail site managers have the potential to be a key stakeholder in transitioning to more sustainable practices.
- Significant volumes of food waste are generated from the food outlets on-site, an average of 0.8 T/week of measured food waste from 22 of 25 food outlets excluding plate waste. Hence there is a significant opportunity to reduce food waste through avoidance programs and harness what is left along with other streams as a resource for potential management on-site.

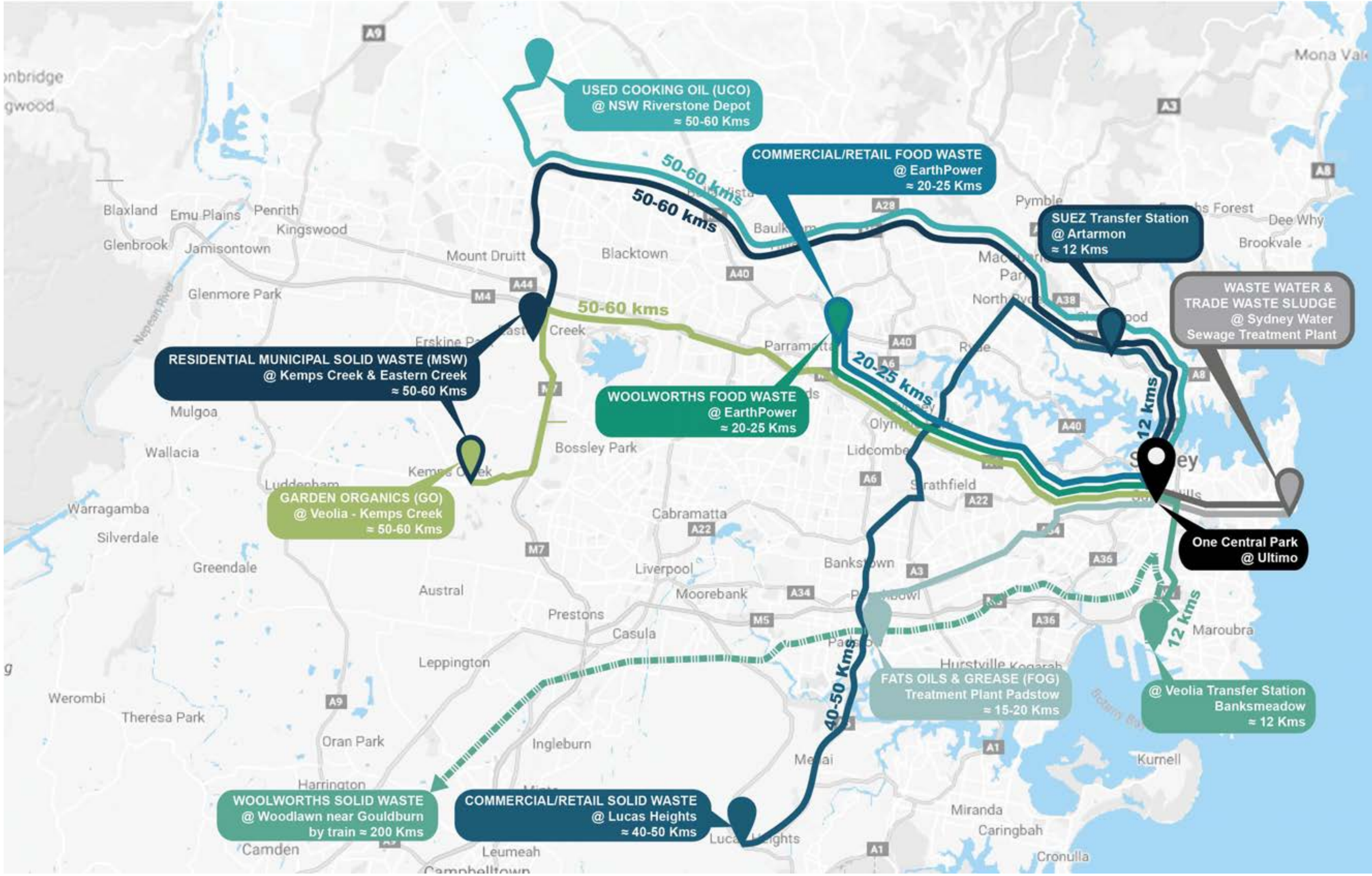
- This includes varying levels of bioenergy potential, which are dependent on the streams theoretically incorporated, refer to Figure 5.7 for one option considered.

Figure 5.6 – One Central Park organics waste streams and destination points

(a) Organics streams

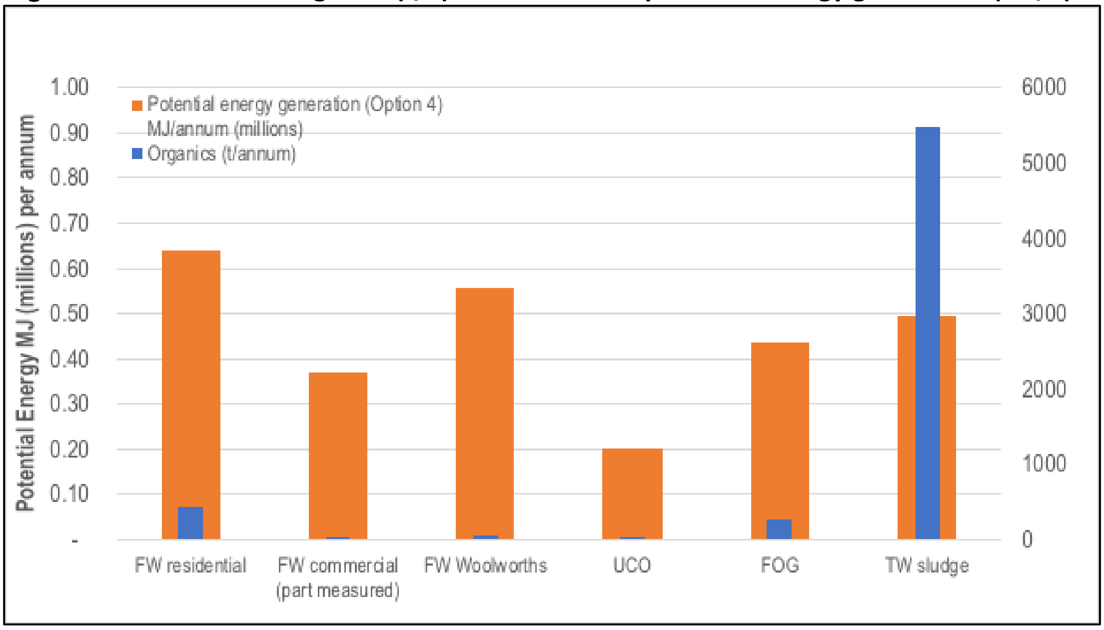


(b) Destination points



(Source: Turner et al., 2018)

Figure 5.7 – Estimated organics (t/a) and associated potential energy generation (MJ/a)

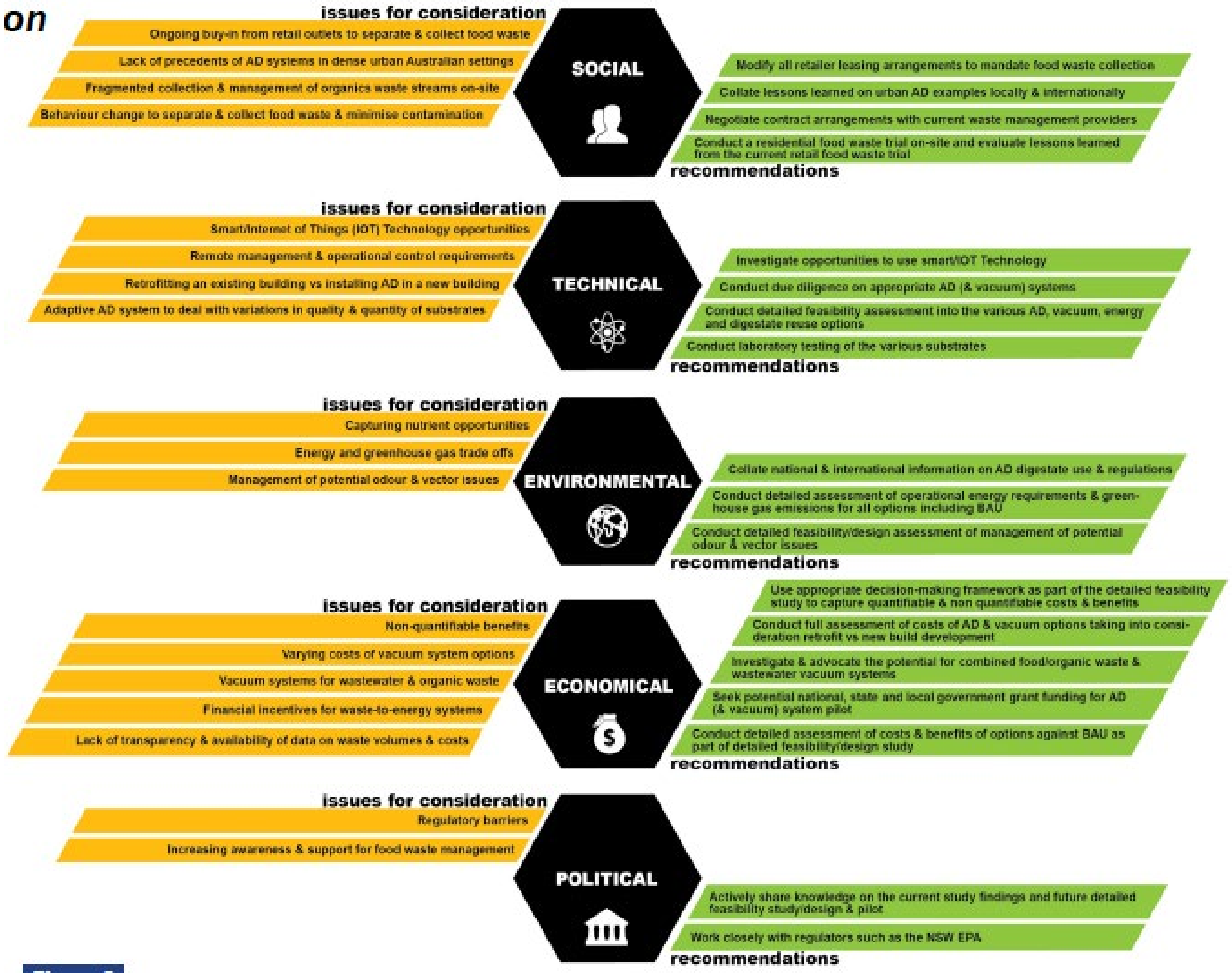


(Source: Turner et al., 2018)

- There are significant opportunities to generate bio energy on-site to offset UOW costs but AD sizing, type of feed stock and collection/transport methods need to be considered to minimise costs (i.e. AD and vacuum) and maximise benefits (i.e. energy potential).
- As much as 20% of the electricity or 50% of the hot water needs could be provided where UOW is used for AD on-site in large mixed use/precinct scale developments such as One Central Park. Avoided waste removal costs could be as much as AUD 85,000/a with similar avoided electricity/hot water costs and the opportunity for additional benefits such as thousands of km of reduced truck/rail movement in the city.
- Due to the lack of demonstration sites using local AD there are an array of social, technical, economic, environmental and regulatory feasibility issues that need to be investigated to proceed with local scale AD, which is still in its infancy globally, with limited examples.
- Whilst a small AD plant can be retrofitted into a building such as One Central Park, vacuum systems which are likely to improve transport efficiency within a large building/precinct and lower food waste contamination risks, need to be considered at the building design stage as retrofitting is cost prohibitive.

A summary of key issues and recommendations from the study are provided in Figure 5.8

Figure 5.8 – Key issues and recommendations from the CP case study



(Source: Turner et al., 2018)

5.3.3 IWC CASE STUDY

5.3.3.1 RESEARCH APPROACH

The IWC case was able to leverage off the methods and analysis conducted in both the PUP and CP case studies. Again a mixed methods approach was used as illustrated in Figure 5.9, which included the key data gathering, analysis and mapping (similar to that conducted in the PUP study) but due to more data being available (i.e. Sydney Water, NSW EPA and IWC data) more detailed analysis and mapping analysis was possible. In addition a more extensive literature review on examples of UOW management was conducted as well as a literature review on decision-making approaches. The research also included the options workshop to discuss potential illustrative options using the hotspot maps generated and detailed costs and benefits analysis for a selection of illustrative options.

Figure 5.9 – IWC case study research approach

(Source: Jazbec et al., 2020a. Reproduced with permission of authors and client)

5.3.3.2 KEY NOVEL APPROACHES AND KNOWLEDGE GAPS FILLED

Key novel approaches and knowledge gaps filled included:

- Similar to the PUP case study, the study brought together various stakeholders and associated data. It enable new analysis methods to be developed to holistically estimate the multiple streams of UOW at the LGA scale.
- The analysis and geospatial hotspot mapping of various streams of UOW at the LGA scale was conducted for the first time in Sydney.
- An estimation of C&I food waste at the LGA scale was conducted for the first time in Sydney due to the use of additional data sets from the NSW EPA and council. This

enabling the testing of new analysis methods which can potentially be used across the city for city-scale analysis.

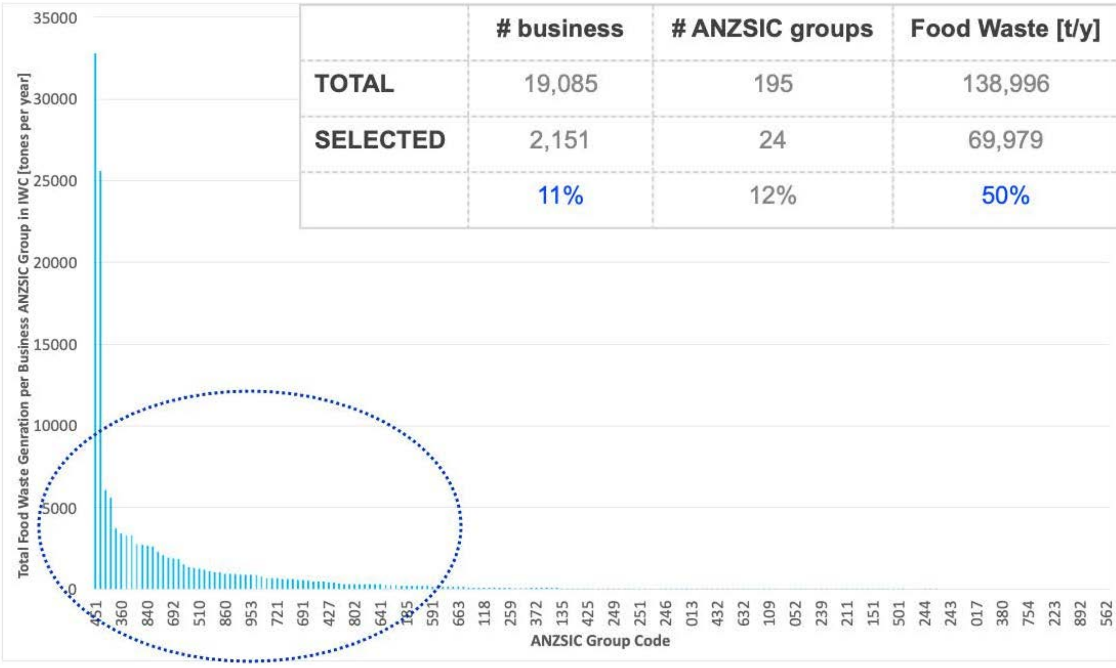
- Collation of a large set of national and international UOW management innovative options at various scales being implemented globally was conducted to facilitate knowledge transfer in the waste industry.
- Costs and benefits analysis of a broad suite of illustrative UOW management options at multiple scales was conducted for first time that can be considered by councils.

5.3.3.3 KEY FINDINGS

Key findings here are limited to those that are publicly available (Jazbec et al., 2021). Other more detailed findings are included in the full report in Appendix D (Confidential). Public findings include:

- To garner a more holistic picture of UOW within an LGA requires collation of disparate data sets, with many difficult to obtain and subject to privacy issues. This making it difficult to firstly garner a holistic picture of UOW at the LGA scale and secondly determine how to manage it. However, there are significant opportunities for data mining and associated management of multiple streams of UOW.
- There is a significant lack of data in C&I UOW data and associated measurement but it is possible to estimate based on a combination NSW EPA BinTrim auditing data, Sydney Water records and council ATO and ANZSIC records.
- From analysis it is estimated that residential and C&I food waste is a large component of UOW. Of the nearly 20,000 businesses registered in the LGA examined, only approximately 11% are responsible for 50% of the estimated food waste when assessed by ANZSIC code grouping (i.e. accommodation and food services, trade, manufacturing). Whilst this is only an estimate it is a useful way of highlighting were to focus food waste avoidance, separation and treatment programs to help achieve UOW targets, refer to Figure 5.10.

Figure 5.10 – Non-residential food waste generation (t/a) estimates by ANZIC grouping



	# business	# ANZSIC groups	Food Waste [t/y]
TOTAL	19,085	195	138,996
SELECTED	2,151	24	69,979
	11%	12%	50%

(Source: Jazbec et al 2020. Reproduced with permission of authors and client)

- Whilst councils own and/or manage a large proportion of institutional sector buildings/properties there is a surprising paucity in data on UOW generated/managed, which could be filled by council investigations, helping government lead by example.
- Even within one LGA there is significantly different urban form (i.e. SDs versus MUDs versus mixed use and C&I) with each lending themselves to different UOW management options (i.e. not one size fits all).
- Between the 2017 (PUP) and 2020 (IWC) document and literature reviews on innovative UOW management at various scales there has been significant growth in socio-technical options available and examples of implementation globally.
- When considering whole of society costs and benefits, options such as avoidance, composting at home and commercial on-site management have some of the lowest NPV costs and opportunities for GHG reduction. While FOGO has one of the higher NPV costs.

In the next three Sections, 6.0, 7.0 and 8.0 (in Part IV) I conduct a meta-analysis using water IRP as a heuristic. This to help think through and demonstrate at both a conceptual and practical methods level how IRP, strengthened by systems thinking and sustainability transitions, could potentially fill some of the identified gaps and opportunities in UOW management planning, analysis and decision-making.

PART IV:

IRP META-ANALYSIS

The following Sections 6.0, 7.0 and 8.0, build on summary Table 3.5, which identifies:

- the waste management planning gaps and opportunities in Section 2.5
- the first 3 core IRP Steps relevant to those gaps and opportunities introduced in Section 3.2 and their current strengths to fill those gaps
- how each step might be strengthened by systems thinking and/or sustainability transitions introduced in Sections 3.3 and 3.4.

Drawing on the Sydney-based nested case studies summarised in Sections 4.0 and 5.0, I investigate further, as illustrated in Figure PIV-1. This is achieved by conducting a meta-analysis using water IRP as a heuristic. In each case I use water IRP to help think through and demonstrate at both a conceptual and practical methods level how IRP (strengthened by systems thinking and sustainability transitions where necessary) could fill some of the identified gaps and opportunities in waste management planning.

These sections of the thesis aim to advance UOW management planning, analysis and decision-making. They also aim to advance water IRP practice where relevant. Figure PIV-2 identifies where the gaps and opportunities are predominantly discussed within Sections 6.0, 7.0 and 8.0 (i.e. IRP Steps 1, 2 and 3).

Case studies were conducted using selected elements of the IRP framework to demonstrate the concepts and methods used in IRP applied to UOW management, many for the first time. As all IRP steps were not utilised in the individual case studies, not all the identified gaps and opportunities are filled due to the project-based nature of the case studies. Notwithstanding, the meta-analysis provides valuable insights to help advance UOW management planning, analysis and decision-making from both a conceptual and practical methods level.

In each of Sections 6.0, 7.0 and 8.0, I aim to:

- reiterate the key gaps and opportunities identified and how they manifest in the emerging complex UOW management sector, especially in Sydney and Australia
- conceptualise at a high level how IRP, potentially strengthened by systems thinking and/or sustainability transitions, might be used in UOW to fill those specific gaps and opportunities using water IRP examples
- demonstrate from the case studies the testing of various methods based on IRP and/or systems thinking and sustainability transitions that could fill the identified gaps and opportunities at a practical methods level

- discuss the potential application for UOW IRP and, in some cases, broader water IRP.

In each subsection I specifically use water IRP examples as part of the meta-analysis heuristic due to: (1) my extensive direct experience in water IRP, (2) the numerous conceptual and practical examples available within water IRP and (3) the lack of conceptual and practical examples in waste IRP to draw from.

Figure PIV-1- Meta-analysis of UOW using water IRP as a heuristic

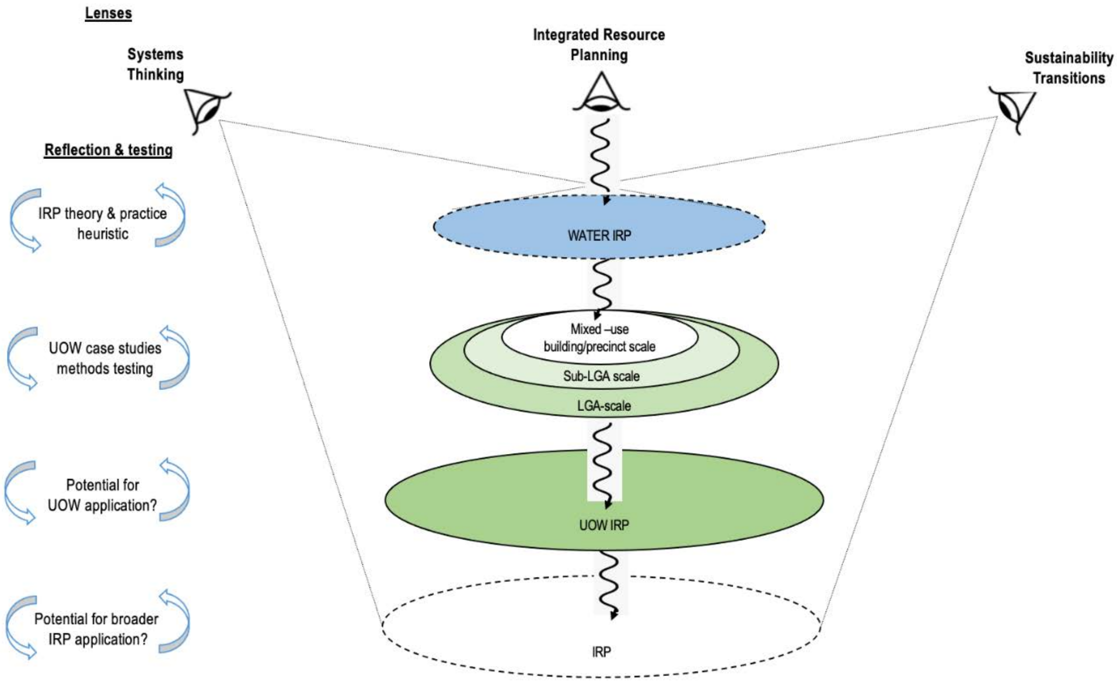
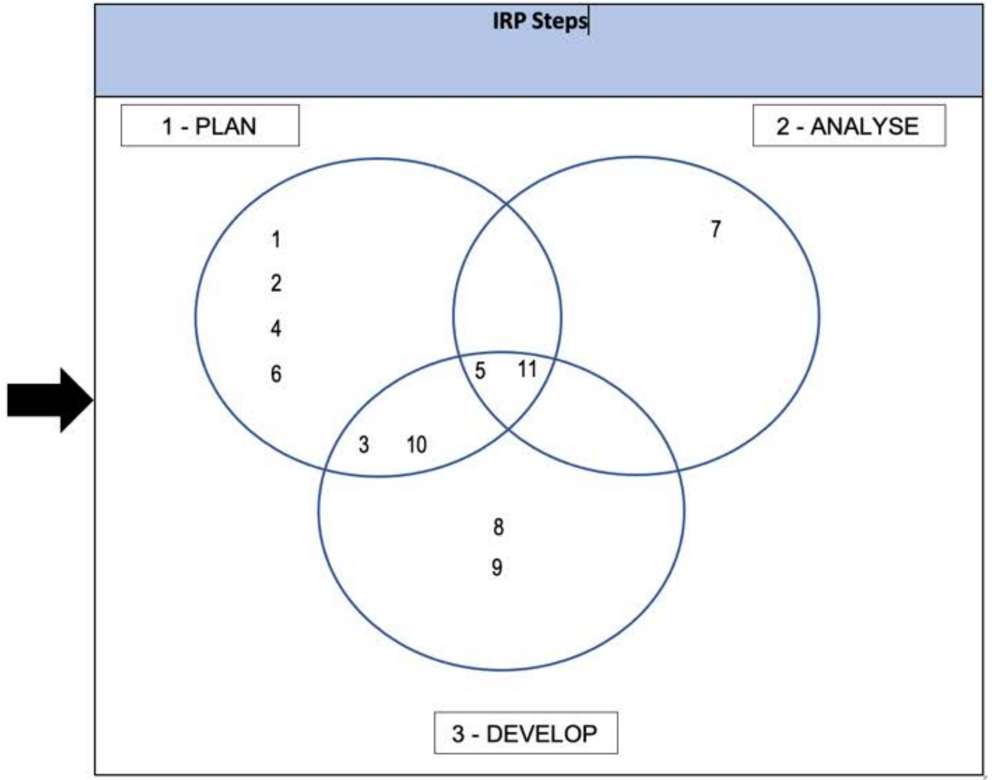


Figure PIV-2– Focus of gaps & opportunities discussed in IRP Steps 1 to 3

Identified waste management planning gaps/opportunities (identified in Section 2)
A need for approaches that better incorporate/consider: 1. a broader and deeper **socio-technical systems perspective** 2. multiple and often conflicting **objectives** and **criteria** relevant to the specific characteristics of UOW 3. **cross-sectoral impacts** and **trade-offs** 4. the diverse **stakeholders** involved in generating and managing UOW to more effectively account for stakeholders and **social perspectives** 5. **MCDA features** that work through objectives/criteria, the specific context and an array of potential solutions **iteratively** (i.e. value-, context- and alternative- focused thinking) 6. the **specific context** and **socio-technical system** of the jurisdiction being investigated 7. sufficient **contextual detail** to inform decisions despite the significant **data gaps** 8. a broader **network of complementary options,** that take into consideration **drivers and pressures**, 9. more adequately **preserve resources** (i.e. **prioritise avoidance)** 10. the risk of **LTS lock-in and adaptive management and innovation lock-out** 11. integration of **GIS/visualisation** techniques and even game-theory to assist in better understanding complex WM systems and **engage stakeholders** to improve decision-making



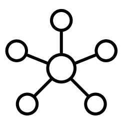
6 FRAMING THE OVERALL PLANNING INVESTIGATIONS (IRP STEP 1)

Section 2.0 identified the gaps and opportunities associated with the initial framing of waste management planning, analysis and decision-making investigations, that is, activities within Step 1 of the Turner et al. (2010) IRP framework. This Section specifically considers how UOW planning can be improved through better consideration of those gaps associated with the:

- system(s) being investigated
- diverse stakeholders directly and indirectly involved
- key services provided and goals/objectives and broader context.

Due to its inherent systems-thinking foundation, IRP is particularly strong both conceptually and methodologically when defining the system and considering the stakeholders involved. It is also strong when considering the key services or function of the socio-technical system being examined, the goals/objectives and broader context. However, due to the complexity of UOW, each of these facets could be strengthened in practice through augmentation with specific systems thinking and sustainability transitions methods. These concepts and methods, tested in the Sydney-based case studies, are discussed in the following sections.

6.1 GARNERING A BROADER & MORE GRANULAR SYSTEMS PERSPECTIVE



As identified in Section 2.3.8, both integrated and sustainable waste management approaches highlight the importance of a 'systems' perspective including the various components, sub-systems and inter-relationships. This applies to both developed and developing countries (MacDonald, 1996; McDougall et al., 2001; Van de Klundert & Anschutz, 2001; Marshall & Farahbakhsh, 2013). Indeed, waste management techniques such as LCA are founded on systems concepts (Edwards, 2017; Onat et al., 2017).

Due to the unique characteristics of organics, however, many jurisdictions now realise the need to manage organics separately as part of a biological 'system', in line with the circular economy (EMF, n.d.). This shift to a biological systems perspective brings other organic waste streams within the urban environment to the fore, such as wastewater biosolids and fats, oils and grease from grease traps. That is, the other organics streams along the value chain (refer to Figure 3.7) and beyond food waste and garden organics in residential bins, which have traditionally been the main organics focus of the waste management sector. This shift in systems perspective leads to the need to reframe organic waste. This both in terms of a broader bio-based socio-technical system involving multiple organics streams that cross different industry sectors (i.e. wastewater and agriculture) as well as having a more detailed systems view of the various organics system components, sub-systems and their interactions. As highlighted by Spang et al. (2019) for food waste, observing a broader and more detailed system enables a move away from silver bullet solutions towards a more diverse mix of context-relevant solutions.

UOW planning, analysis and decision-making could therefore be significantly strengthened by using both a broader cross-sectoral and more granular systems perspective, along with more clarity around boundaries. This is especially true in large urban environments such as Sydney. Sydney in particular illustrates the highly fragmented management of UOW streams and inconsistent consideration of boundaries, as discussed in Sections 1.1.2 and 4.1. When waste streams and boundaries are defined, they are often narrow. This limits the system observed and the options considered, obscuring the potential positive and negative impacts with other interconnecting systems. For example, metro councils in Sydney typically confine their assessment of organics to the residential sector they are accustomed to managing and responding to the Waste and Resource Recovery Act 2001 (NSW Legislation, 2001). This partial view of the UOW streams and sectors and sub-sectors generating such materials limits the assessment of UOW management opportunities in LGAs. This highlighted by the CP and IWC case studies which illustrated other UOW management options possible when opening up the systems and boundaries considered, especially those relating to the non-residential sector and localised energy generation within LGAs (Turner et al., 2018; Jazbec et al., 2020a). At a national scale, although other residential and non-residential organics streams are included in waste reporting (Pickin et al., 2020), they are typically considered separately. Indeed some organics are not brought into the picture at all, such as used cooking oil. This is despite its omnipresence in the urban environment and significant potential for valuable end uses/products ranging from animal feed to biodiesel (Teixeira et al. 2018; Scanline, n.d).

As identified in Section 3.2, understanding the core socio-technical system (and sub-systems) being investigated together with the boundary of analysis is fundamental in IRP. This stems from its operations research lineage and is a shared systems thinking tenet. Such systems are observed as both ‘hard’ and ‘soft’ and interconnected with other industry sector systems. Consistently observing the core socio-technical system, sub-systems, boundaries, linkages and impacts is crucial to IRP investigations and one of its key planning strengths.

As identified in the introduction to Sections 6.0, 7.0 and 8.0 due to my experience in water IRP, the extensive use of water IRP internationally and the absence of examples of waste IRP, water IRP has been used here in each Section/Sub-section to draw on conceptual and practical examples.

When examining systems and boundaries in water IRP, the physical water system is often clear as it is the ‘hard’ pipe network and associated assets servicing the customers in a city or town with typically only one main utility/service provider. The ‘soft’ system is represented by the customers on the other side of the reticulated system water meters and their connection with end uses/micro-components within their homes (i.e. toilets, showers) and other distributed systems (e.g. rainwater tanks). Such observation of both the hard LTS and more granular soft socio-technical system embedded within it, is commonly practiced in water IRP. This dual holistic and detailed systems perspective is instrumental in helping to shift water planning to observe efficiency/conservation potential and demand-side options.

However in UOW, the socio-technical systems and boundaries are less obvious. Sydney provides an example of such ambiguity around basic systems, their boundary definitions and lack of alignment between government body definitions, utility/essential service areas and various associated datasets. For example with respect to boundaries alignment varies between waste levy areas, wastewater networks, waste management collection/treatment regions, ABS population areas, LGAs and defined growth areas (refer to Section 4.1 for further details). With water/wastewater managed predominantly by Sydney Water, residential waste managed by over 30 individual councils and non-residential waste managed by numerous private entities this lack of alignment of basic boundaries compounds difficulties around UOW data collation and analysis and resource management.

In addition, the various components of the socio-technical system embedded within the UOW LTS system are not viewed holistically (as advocated in systems thinking and IRP), such as householders and their home composters or individual businesses with on-site dehydrators. In fact, unlike water IRP, there is little effort in gaining collective knowledge about these embedded socio-technical system assets despite their significant and growing numbers.

Instead, there is more focus on the hard incumbent LTS collection and treatment system and associated modifications (i.e. transitioning organics from the current residual waste bins to FOGO collection and treatment). Such incremental system change (i.e. from one LTS to another) is commonly observed in sustainability transitions where LTS remain dominant and effectively lock-out innovation and adaptive management (Geels, 2010; Unruh, 2000).

Looking further into boundaries, in water IRP there are many examples of how expanding the system boundary of analysis and appreciating the interconnections between various cross-sectoral systems can, as highlighted in systems thinking, unveil emergent functionality, cross benefits and unintended consequences. For example, improving water efficiency through efficient showerhead programs helps not only reduce potable water use but also hot water use, energy use, GHGs and customer bills. It also reduces the volume of wastewater pumped, treated and discharged to sensitive receiving waters. Hence, clearly linking potable water with energy and wastewater systems and the associated benefits (Turner et al., 2007). On the flip side, however, other intervention programs such as rainwater tank regulations and rebates used to reduce potable water were originally found to increase the energy intensity of water provided due to poor pump-system configurations and lack of maintenance. This illustrates the unintended consequences of a policy intervention aimed at the primary goal of saving water (with the added benefit of reducing stormwater runoff) considered within limited system boundaries (i.e. not considering the impacts of energy) (Retamal et al., 2009).

In UOW, the historically narrow view of focusing on food waste and garden organics in residential waste, limits the system view and interconnectivity, thus obscuring the potential opportunities as well as risks of unintended consequences. Hence, there are significant benefits of using an IRP or systems thinking approach that can be gained by expanding the boundary of analysis to:

- residential and non-residential generators of UOW
- multiple streams of organics within the urban environment (e.g. food waste, wastewater and fats, oils and grease) and how they are managed at various scales
- interconnecting systems (e.g. wastewater, energy and agriculture).

This expansion of the system and associated boundaries enables decision-makers to appreciate interconnections and achieve new cross-sectoral targets and circular economy objectives while helping to avoid unintended consequences. An example of this can be drawn when considering the nexus between waste and wastewater.

AD co-digestion of food waste and fats, oils and grease from grease traps with wastewater sludge is used in many countries to generate bioenergy, although examples are sparse in Australia and are only beginning to be investigated (Jazbec et al., 2023; Jazbec et al., 2020c; Kaparaju et al., 2023). Using wastewater treatment plant assets with AD capacity in the fragmented waste management sector has the potential to achieve multiple benefits. These include contribution to cross-sectoral objectives and targets for bioenergy generation and GHG reduction (DPIE, 2021a), identified waste management AD asset needs (DPIE, 2021b), increased nutrient recovery, and capital savings through combined waste-wastewater-energy asset optimisation (Jazbec et al., 2023; Kaparaju et al., 2023).

However, as an example of unintended consequences, discharging food waste, used cooking oil and fats, oils and greases directly to sewers, (e.g. using an InSinkErator), can result in pipe corrosion due to hydrogen sulphide build-up and cause major blockages (i.e. fatbergs) when mixed with materials such as wet wipes. Although, these issues are dependent on various factors such as climate, system characteristics, and discharge volumes (Fam et al., 2017; Turner et al., 2017; Zan et al., 2021). Blockages cost millions of dollars in additional maintenance for utilities and are a significant concern both in Australia and internationally, creating the need for new 'flushability' standards (Fam et al., 2017; Ruddick, 2021). Utilities such as Sydney Water have some control through licensing over non-residential food waste and fats, oils and greases entering the wastewater system. However, they have little control over households using InSinkErators, and little is currently known about the quantum of fats disposed to sewer.

Hence, branching beyond the usual narrow UOW streams and system boundaries using IRP and systems thinking can assist in identifying both potential benefits as well as negative impacts not normally considered.

6.1.1 CASE STUDY EXAMPLES

There are limited public examples in Australia of UOW analysis going beyond food waste and garden organics using a broader and more granular systems perspective. This gap is filled to varying extents by the case studies. All three case studies used specific physical system boundaries (i.e. mixed-use building/precinct, sub-LGA, LGA). They expanded the system beyond just residential food waste and garden organics to other organic streams within the residential and non-residential sectors including used cooking oil, fats, oils and grease from grease traps, wastewater, trade waste and even pet waste. The boundaries were also expanded to other interconnecting sector systems to consider energy generation, nutrient-recovery and GHG emissions. Each case study varied depending on the scope, data available and stakeholders involved. The first case study commenced in 2017 when there was a significant paucity of UOW data in Sydney, especially in the non-residential sector. While the three case studies have assisted in filling this gap, it is still acknowledged as a major issue that needs to be addressed as discussed further in Section 7.1.

Table 6.1 illustrates the various systems and boundaries explored for each case study. The specific research questions, analysis and findings for each of the nested case studies are summarised in Part III Section 5.0.

Table 6.1 Organics streams & geographical & cross-sectoral boundaries of the Sydney-based nested case studies

Boundaries	Case studies					
	CP		PUP		IWC	
	R	NR	R	NR	R	NR
Organics streams						
- food waste	√	√	√	√	√	√
- garden organics	√	√			√	√
- used cooking oil		√			√	√
- fats oils and grease		√		√		√
- wastewater	√	√	√	√	√	√
- trade waste	√	√				
- other (e.g. pet waste)	√				√	
Other boundaries						
- building/precinct	√	√				
- sub-LGA			√	√		
- LGA					√	√
- energy generation	√	√				
- energy/hot water needs	√					
- GHG reduction					√	√
- nutrient recovery					√	√
- cost and benefits	√	√			√	√

Notes: R – residential, NR – non-residential, CP – Central Park, PUP – Pyrmont-Ultimo Precinct, IWC – Inner West Council, Green – considered, amber – partially considered, white – N/A or not considered

6.1.1.1 BUILDING/PRECINCT SCALE

The CP case study provided, for the first time in Sydney (and seemingly Australia), publicly available details of the variety of organic and organic-rich materials in a mixed-use building/precinct scale development. It also, for the first time, considered the potential feasibility of building/precinct scale AD and the potential bioenergy generation and hot water needs for such a development. This is important, especially for Sydney, due to the sheer number of similar building/precinct scale developments being built and planned over the coming years and both the waste management challenges and opportunities of such developments. By drawing the system boundary at the building/precinct scale, data could be more easily collated on the organics streams and cross-sectoral costs and benefits for those stakeholders involved and able to take some form of action to move towards more sustainable UOW management practices. This provides an invaluable dataset and case study example for future mixed-use building/precinct scale UOW investigations while data on addition examples are collated.

6.1.1.2 COUNCIL/LGA SCALE

At the other end of the spectrum, the IWC case study set the boundary at the LGA scale. This was a first for Sydney (and again, seemingly for Australia) for the various organic and organic-rich residential and non-residential streams at such a granular level. The additional streams of used cooking oil, fats, oils and grease from grease traps, non-residential food waste and wastewater biosolids are not normally considered by councils as they are traditionally outside their waste service obligations and business models. The study also covered the potential GHG reductions and nutrient-recovery opportunities as well as costs and benefits of various options from both the council financial perspective and whole-of-society perspective within the LGA.

Councils in the Sydney metro area who have made bold commitments to stretch targets of zero waste in the coming years may find this expansion of system boundaries particularly useful for achieving such commitments, and/or achieving national and state organics and other cross-sectoral targets by 2030 and beyond.

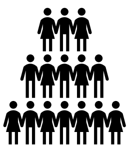
6.1.2 BROADER IMPLICATIONS

The case studies help demonstrate some of the benefits of using IRP and systems thinking concepts and methods for advancing UOW planning, analysis and decision-making by using specific geographical boundaries, broadening the streams considered beyond merely residential food waste and garden organics, and expanding the systems considered to interconnecting sector systems.

The case studies capture a much broader but also granular view of how UOW is generated, the kinds of UOW options available, and examples of the potential cross-sectoral benefits and impacts. These assessments well beyond others in Sydney and equivalent dense urban areas in Australia. Importantly, this shift in systems perspective and boundary definition enabled both more holistic and detailed observation and investigations of the UOW in question. Although due to lack of waste management data, innovative data collation and analysis methods are required to assist in such investigations, as discussed in Section 7.0.

With current policy focusing on the circular economy and net zero emissions in Australia (CoA, 2019; CoA, 2022; Prime Minister - Minister for Climate Change and Energy, 2000) and worldwide (UN, n.d.), such consideration of systems, sub-systems, interconnecting systems and clear articulation of associated consistent boundaries would be invaluable in UOW planning and decision-making. Despite the current fragmented waste management system and limitations in data to expand such boundaries of analysis, the use of IRP and systems thinking approaches are useful at multiple scales of analysis (e.g. from building/precinct to LGA to city) and thus warrant further testing and application. This is especially the case at the precinct/building and LGA scales where a lead stakeholder may have some form of control or potential for a leadership role, as discussed further in Section 6.2 below.

6.2 CONSIDERING DIVERSE STAKEHOLDERS



Section 2.5 highlights the gap in effectively considering stakeholders in waste management planning and decision-making. Morrissey and Browne (2004) raised this as a gap at the start of the century and Asefi et al. (2020) still raised it as a concern two decades later. The gap prevails despite the availability of approaches such as integrated sustainable waste management (Anschutz et al., 2004), used predominantly in developing countries to help overcome such deficits in challenging urban environments. Due to the complexity and fragmentation of the emerging UOW sector, in terms of diverse streams and multiple public and private stakeholders generating and managing organic materials at multiple scales, this gap needs to be addressed more than ever. Doing so would aid more effective and co-ordinated UOW management planning, analysis and decision-making.

In IRP, due to the need to involve stakeholders during various parts of the process, stakeholders are considered upfront, in Step 1 of the IRP framework. In water IRP, generally it is clear who the key stakeholder is in conducting a planning exercise, decision-making and subsequent investment in new demand and/or supply-side solutions. Typically in water, they are the utility or council responsible for the main hard system water/wastewater network in a particular jurisdiction. They normally supply the majority of, if not all, customers with water/wastewater services. In Sydney however, partly due to the drought in the early 2000s, this has become more complex. The NSW Government co-ordinates the water strategies for multiple stakeholders (NSW Government, n.d.). This includes the state-owned Sydney Water and WaterNSW, the key stakeholders that manage the majority of water/wastewater services for Sydney as well as the bulk water supply from dams. The stakeholders also include new private operators (such as the managers of the Sydney Desalination Plant) and various water recycling systems of various scales within the city, as well as other government departments and non-government stakeholders. This co-ordinated stakeholder approach is now used in several major cities around Australia.

In UOW management, the key stakeholder planners and decision-makers are more opaque. This is especially the situation in larger cities like Sydney, where multiple stakeholders are involved in the UOW management system from generation, collection and treatment through to disposal or use of the end product. Specifically relating to Sydney, the NSW Government has co-ordinated the new waste strategy to assist NSW in transitioning to a circular economy over the next 20 years by working with multiple stakeholders (DPIE, 2021a; 2021b). The strategy includes ‘organics’ as a core waste stream that needs to be addressed to help achieve state-based waste management targets. The NSW Government have invested part of the waste levy in demand- and supply-side solutions for organics from education programs through to co-funded centralised LTS. However, in Sydney, unlike water, this means the NSW Government relies heavily on private sector stakeholders to fund/co-invest in the equipment needed (DPIE, 2021b). This is mainly because few of the 35 amalgamated metro councils actually own their own facilities since privatisation of the key infrastructure and assets in 2010 (LGNSW, 2017). Interestingly this not the case in regional areas, where core assets are mainly still owned by councils. Hence, despite the government developing a 20-year waste strategy, setting targets and providing funding, it does not have the same level of ‘control’ as a planner/decision-maker using IRP in other essential services such as water.

Such fragmented UOW planning and decision-making creates a challenge in complex urban areas. However, these difficulties can be overcome by acknowledging the importance of stakeholders in the planning and decision-making process, as in IRP (Tellus, 2000; International Rivers, 2013). Although, as similarly found in MCDA (Marttunen et al., 2017), the IRP process likely warrants bolstering in terms of structured systems thinking methods such as stakeholder analysis (Grimble & Wellard, 1997). Stakeholder analysis is a common soft systems/soft operations research/problem structuring method (Leleur, 2012) as identified in Section 3.3.1 Box 4. Such methods help provide greater clarity on the stakeholders directly and indirectly involved and thus in UOW management, provide the opportunity to ascertain how they can be more effectively identified and engaged in planning, analysis and decision-making as well as implementation.

With the acknowledged gap in considering stakeholders effectively in waste management approaches and the complexity of UOW and its fragmented management, it would be highly valuable to use stakeholder analysis to help unveil the myriad of stakeholders potentially involved. This, especially considering how UOW stakeholders vary from jurisdiction to jurisdiction due, for example, to the varying:

- governance structures (metro versus regional)
- levels of asset privatisation
- extent of adoption of new types of socio-technical UOW management at various scales.

6.2.1 CASE STUDY EXAMPLES

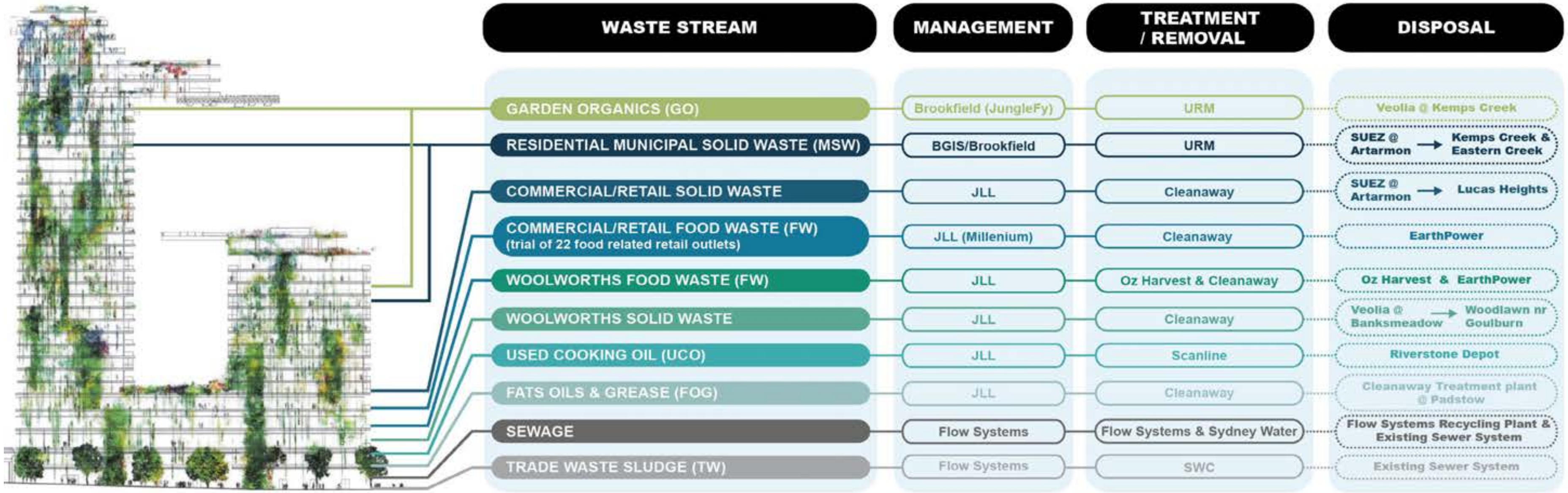
All three case studies demonstrate various useful examples of stakeholder analysis. The demonstrated examples are outlined below.

6.2.1.1 STAKEHOLDER IDENTIFICATION

Stakeholder identification was conducted for both the CP and the IWC case studies.

For the CP case study, Figure 6.1 illustrates the identification of the numerous stakeholders involved in the management, treatment, removal and disposal of the various streams of organics and organic-rich materials within just one mixed-use building/precinct scale development in Sydney, One Central Park. It shows that no single entity is responsible for the management of all residential and non-residential UOW within the building, but a complex web of stakeholders linked through contractual arrangements. In terms of the non-residential sector, in this case, the retail manager for the site (JLL) is a key stakeholder that can influence how organics are managed in an existing building. Indeed, JLL assisted in facilitating a food waste separation trial specifically for the retail premises to inform the CP case study. Waste management was unfortunately not considered in as much detail as other sustainability concepts during the design and development stages of the award-winning building (White et al, 2018). A lesson learnt by more recent major developments, such as the multi-billion dollar Barangaroo development in Sydney. Barangaroo is now seen as a leading light on the adoption of innovative on-site waste and organics management in dense urban environments through thoughtful design and operation (Property Australia, 2018,). Such building/precinct scale developments are both a significant UOW management issue (e.g. logistics, scale of waste management, behaviours) but also a major opportunity as demonstrated by the CP case study (e.g. potential for streamlined collection and local energy generation). This is particularly the case in large cities, especially Sydney, where over 50 such precincts are already being built/planned in the coming years (refer to Section 4.2) and represent a major opportunity to help transition to improved UOW management in dense urban environments.

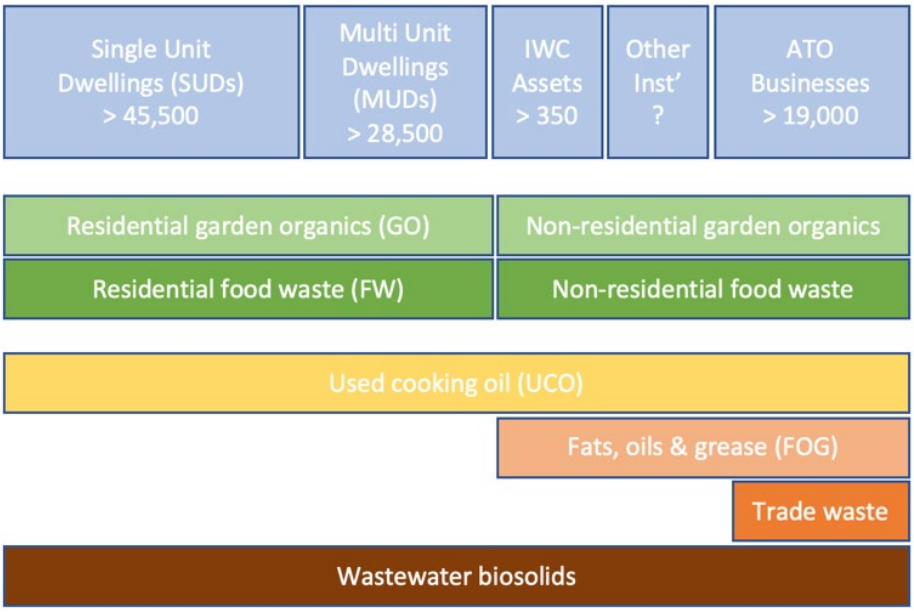
Figure 6.1 – Stakeholders involved in organics management at One Central Park



(Source: Turner et al., 2018)

In the IWC case study, preliminary stakeholder identification helped provide an initial overview of the generators of UOW and customers receiving an UOW service within a typical Sydney metro LGA. This is a broader picture of UOW stakeholder identification not typically considered by councils that normally focus on their residential customers' organic-rich bins and garden organics services where provided.

Figure 6.2 - Simplified breakdown of basic sectors & organics streams in the IWC LGA



As shown in Figure 6.2, through the process of identifying basic sectors in an LGA together with the basic UOW streams, it can be seen that IWC is responsible for managing, through waste contractors, a large proportion of the individual customers serviced (i.e. nearly 74,000 SUDs and MUDs households generating UOW) as well as their own council properties (i.e. childcare facilities and libraries), some 350 assets. They also manage the waste for just over 100 small businesses. However, as indicated there are a significant number of 'other' institutional customers and over 19,000 (Inner West Council [IWC], n.d.) non-residential businesses registered with the Australian Tax Office in the LGA not managed by IWC[18]. Each business generates varying levels of UOW (see Section 7.1 for examples) managed by stakeholders at various scales (e.g. on-site technology providers through to LTS treatment operators outside the LGA). Such disparate stakeholders are not easily identifiable due to the lack of measurement of organic waste at source and lack of co-ordinated registration of organic treatment systems and/or services.

[18] At the time of the analysis in 2019

Figure 6.2 also shows that in terms of organics, IWC may be responsible for managing food waste and garden organics for residential customers but this is only a proportion of the multiple streams of organics within the IWC LGA produced by the various residential customers and non-residential businesses and institutional properties. These other, broader organics are again managed by multiple stakeholders. For example, virtually all wastewater biosolids are managed by Sydney Water, and fats, oils and grease in the non-residential sector are potentially managed by any of the 27 Wastesafe licensed transporters on the Sydney Water compulsory registration system (Sydney Water, n.d.).

Despite IWC not being responsible for managing the UOW of all properties generating organics or even the greatest volume or mass of UOW (i.e. typically limited to residential food waste and garden organics), the identification shown in Figure 6.2 helps illustrate the key role of councils. That is, councils, as a single stakeholder entity, even in metro areas, have significant connection with many individuals within their LGA. Similarly this is the case for Sydney Water in terms of wastewater biosolids. Councils therefore have the potential to play a major role in UOW management, planning and decision-making, especially when considering the potential of demand-side avoidance and smaller scale on-site solutions, core to IRP. This is a potential role both now and in the future, as urban densification unfolds (i.e. through council planning controls). Such councils also have an opportunity to expand that role beyond their current responsibilities (i.e. non-residential customers and other UOW streams) to help meet NSW Government non-residential food waste reduction/separation targets (DPIE, 2021a). Such expanded responsibilities are seen in Europe for example, with respect to the co-ordination of the collection of other UOW such as residential and non-residential used cooking oil (greenea, n.d.).

6.2.1.2 STAKEHOLDER CATEGORISATION & MAPPING

A deeper level of stakeholder analysis was also conducted in the IWC case study. This aimed to further explore stakeholder identification together with categorisation and mapping using a simple control-influence-concern model (Covey, 1997). Five experienced IWC staff in UOW management and sustainability roles were involved in a stakeholder mapping workshop at the start of the study. As part of the workshop, they were asked to identify individual stakeholders/groups along with their assessment of each stakeholder's level of control, influence or concern in UOW generation and management. This information was subsequently overlaid with an assessment of whether the stakeholders identified were federal, state or local government, private organisations, industry bodies or more community orientated. This information not only provided greater understanding of the surprisingly diverse spectrum of stakeholders already directly and indirectly involved in UOW generation and management in the progressive IWC LGA, but also a means to:

- identify a potential group of stakeholders to join the study to provide data
- act as an advisory group to share knowledge and help influence outcomes from the study
- potentially fulfil the council's aspirational goals/objectives due to their respective levels of control of UOW.

Figure 6.3 illustrates the synthesis of the stakeholder mapping exercise.

Such mapping can be further segmented into stakeholders along the value chain. For example, from UOW generators and collectors to treatment managers and end-product users (as depicted in Figure 6.1 for the CP case study). Or mapped according to stakeholders' power versus interest/level affected, within a matrix of low to high (ODI, 2009). Various mapping configurations help refine the view of the complex web of stakeholders involved in the UOW system in any given jurisdiction. Garnering a broad understanding of the stakeholders and their control-influence, power-interest or similar, is useful in complex environments wanting to undertake a planning and decision-making exercise such as IRP. This is also important in situations where multiple stakeholders need to take some form of action to achieve targets, drive innovation and assist in system transformation at multiple scales.

Figure 6.3 – Synthesis of IWC stakeholder mapping workshop

IWC ORGANICS MANAGEMENT STAKEHOLDER MAP 21/11/2018 (Based on Covey 1989 - control, influence, concern mapping)			
Federal/State Gov' Level Stakeholders	**Local Gov' Level Stakeholders**	**Private organisations/Industry bodies Stakeholders**	**Community Level Stakeholders**
CONTROL			
Federal Gov' (as regulator)	IWC LEP team (statutory role before LEP to produce short Local Strategic Planning Statement by 06/19 – show community)	Property developers (e.g. Frasers, Lendlease, Mirvac) net zero buildings & compliance — CI & Cn	Residents
Federal Gov' National Waste Policy/targets	IWC (policy/planning & compliance)	Food retailers + commercial businesses	
Federal/State Gov' Circular Economy EPR (for food producers + manufactures)		Non-residential waste producers (schools, healthcare, community organisations, gov, local gov)	
NSW EPA (organics team - Amanda Kane/Sian McGhie)		Collection crews + contractors (operational – contamination management/check each bin) — CI & I	
NSW EPA & SWC (waste regulators)			
Sydney Water (manager sewer & waste – currently no food waste to sewer)			
INFLUENCE			
Greater Sydney Commission (LEPs need to reflect District Plans – help partner on innovative ideas) — CI & I	LGNSW (dog poo/e-turd)	MUDs Building managers, caretakers, cleaners (operational) (facilities managers & association)	Community pressure
Federal Gov' large scale behaviour change programs (drink driving, tiredness kills, seat belts, plastic waste to sea)	IWC educators, marketing & communications (Prue – IWC engagement officer)	Waste contractors/collectors	Active community groups
	Mayor	Waste industry (reps WACRA + contractors)	Community orgs
		Innovative private sector reps (manage conflict of interest)	
		Organics Industry Associations Process - Waste managers	
		Horticulture (e.g. HIA) for future demand for product — I & Cn	
CONCERN			
ARENA (energy)		Developers — CI & Cn	Community – participating in food waste avoidance (EPA & IWC campaigns)
	SSROC & neighbouring councils (Procurement, policy, planning)	Electricity users/suppliers network	Community groups (pickling)
		Landfill/WtE contractors (feed the beast, reduced gas capture, reduced $ viability)	
		Chamber of commerce (currently a shift to a stronger group)	
		Climate council Cities power partnership	
		Food banks	
		Major businesses/retailers producing waste env, $, CSR concern – ugly fruit campaign	
		Alternative Technology Association ATA/RENEW	

*Some stickies were placed in for example both control & influence. Where this occurred this has been labelled (i.e. CI = control, I = influence, Cn = concern)

(Adapted from Jazbec et al., 2020b. Reproduced with permission of authors and client)

6.2.1.3 STAKEHOLDER MOTIVATIONS

An additional facet of stakeholder analysis not explicitly used in IRP but useful in UOW management, due to its complexity and the purported intent for the industry to transition to improved resource use, was to explore the motivations of the stakeholders involved. Mourad (2016) identifies this as important for food waste avoidance. While the motivations of stakeholders were not investigated in the CP or IWC case studies, face-to-face, semi-structured interviews of a diverse selection of stakeholders involved in the PUP case study were conducted. The diverse group of stakeholders from state and local government, public and private utilities, waste management providers and technology providers were asked about what UOW streams they managed/were involved with and their motivations for using innovative UOW management solutions emerging at the time (i.e. in 2017).

Such insights across a broad selection of stakeholders (summarised in Figure 6.4) highlight that even in 2017, it was necessary to consider UOW beyond the traditional waste hierarchy. Only the NSW Government mentioned the waste hierarchy as a motivation, identified as the primary guide for planning and options consideration across Australia at the time (Giurco et al., 2015). Indeed, the stakeholders interviewed identified far broader economic/financial, social and environmental motivations, as also found by Mourad (2016) in similar interviews in the US and France at that time. Such insights help to inform broader goal/objective and criteria setting for any UOW management planning that aims to go beyond LTS centralised solutions and help embrace innovative socio-technical approaches at multiple scales. This as advocated by IRP and seemingly the intent of the NSW Government with past and current funding. Investigation of stakeholders' motivations and values is a key activity found in MCDA (i.e. value-focused thinking), as discussed in Section 2.3.6.

The interviews were conducted in 2017. This was before the major policy shifts identified in Section 1.2, when the waste hierarchy was still clearly identified as the key guide for waste management planning and before the term 'circular economy' became embedded in the Australian waste lexicon. If these interviews were repeated in 2021-22 at the time of writing, the circular economy, and its multifaceted and somewhat ambiguous meaning (Korse, 2015; Geissdoerfer et al., 2017), would likely be an additional goal/objective for some of the stakeholders interviewed. Similarly, due to the recent release of the NSW 20-year waste strategy, the food waste and organics targets and net zero emissions targets would likely be more prominent themes. This highlights that motivations and associated goals/objectives within planning cycles can change in environments that are rapidly changing and this should be considered in order to keep planning exercises, which can often be drawn out, relevant. The City of Sydney council is an example; strategy documents released in 2017 only mentioned the circular economy once, but by 2021 a broader strategy mentions it multiple times and embeds it in future directions and actions (City of Sydney, 2017; 2021).

Figure 6.4 – Identified stakeholder drivers and motivations from PUP interviews

KEY STAKEHOLDERS	ORGANIC WASTE STREAMS						KEY DRIVERS/MOTIVATIONS													
							Waste hierarchy		Economic/ financial					Social/ Environmental						
	GW	FW	UCO	FOG	WW	TW	Economic grants & disincentives to reduce organics to landfill	Waste avoidance/recovery & energy targets	Access to grants to cut capital costs	Reduce waste costs	Reduce energy costs & potentially make money (e.g. AD, digestate, co-locate business)	Profit	Market differentiation	Internal organizational targets (e.g. reduce waste, energy)	Corporate social responsibility obligations	Meet public expectations on environmental issues due to increased awareness	Desire to improve environmental outcomes and resource recovery	Reputation with staff, customers, peers/competitors	Reduce smell/vermin/traffic congestion in city	Knowledge sharing
State government/ regulator	√	√					√	√												
Councils	√	√							√	√				√		√	√		√	√
Businesses	√	√	√	√	√	√			√	√		√	√	√	√	√	√		√	
Waste management providers	√	√	√	√					√	√	√	√	√				√			
Tech providers		√							√			√	√							
Public utility					√	√					√		√	√	√	√	√	√		
Private utilities					√	√			√	√	√	√	√	√			√			

6.2.2 BROADER IMPLICATIONS

The stakeholder analysis investigations conducted as part of the case studies demonstrate the complexity of UOW and the potential benefits of unveiling a deeper understanding of the stakeholders involved. The case studies also highlight the benefits of more structured investigations strengthened through a range of methods used in systems thinking (i.e. stakeholder analysis in the form of identification, categorisation, mapping and motivation investigations). By using these methods within a planning and decision-making approach such as IRP, especially during the initial stages of the planning exercise (i.e. IRP Step 1), it is possible to find stakeholders that can:

- take a leading role
- be involved at critical junctures
- assist in improving data for analysis
- share knowledge on innovative waste management practices
- act to achieve aspirational UOW management targets.

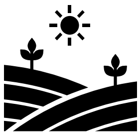
With so many councils identifying ‘zero waste’ and ‘net zero emissions’ targets in their areas in Sydney (City of Sydney, 2017; Inner West Council, 2018) and the NSW Government setting various organics and emissions targets (NSW DPIE, 2021a; NSW DPIE, 2020b) greater clarity is needed on stakeholders and their roles. This includes both the stakeholders generating waste and those managing it at various scales. This helps to garner greater clarity on the socio-technical UOW management system within an LGA and how to manage it more effectively going forward.

The number of stakeholders involved in managing UOW will vary between jurisdictions. Some areas have a limited number of stakeholders and others a complex network at multiple scales. In metro areas such as Sydney, retail managers of large mixed-use building/precinct scale developments have an opportunity to play a key role in UOW management. This is also the case for councils in metro areas with respect to existing customers and those beyond their current control (i.e. non-residential customers). This is even more the case in regional areas where councils are typically responsible not only for waste but also the water/wastewater systems and thus have the opportunity to play a central role in cross-sectoral organics management planning and decision-making (i.e. AD co-digestion and energy generation).

Using structured stakeholder analysis within planning frameworks such as IRP has the potential to unveil key contextual differences between jurisdictions. Incorporating structured stakeholder analysis methods, specifically for UOW, within an IRP approach, could be highly beneficial in unpacking the growing number of stakeholders involved, and importantly, how they can actively assist in advancing UOW management practices. This through an array of solutions including demand-side solutions potentially at a more local scale as advocated by IRP. The stakeholder analysis methods used, based on workshops and semi-structured interview techniques, and focusing on identification and categorisation and mapping, are fairly rudimentary compared to the growing body of literature on stakeholder analysis. Hence there are significant opportunities to further explore such research and incorporate the growing range of methods available in practical decision-making approaches such as IRP.

The specific benefits of strengthening stakeholder engagement methods within the planning process are explored separately in Section 8.1.1.

6.3 CLARIFYING THE BROADER CONTEXT



Another recurring gap/opportunity identified in Section 2.5 is the importance of understanding the broad context in which a planning exercise is conducted, as it can have significant implications for the solutions developed (Mourad, 2015; Iacovidou & Voulvoulis, 2018; Spang et al., 2019). This needs to be considered not only in terms of the physical geography, infrastructure, population growth and climate, but also other aspects drawing from sustainability transitions. These include for example the policy environment, governance structures, social and cultural norms and levels of acceptance, economic and market stability, regulatory requirements and environmental sensitivity and limits. As highlighted in Section 1.1, the context of global waste management has evolved significantly over the last five years or so. This, and related drivers and pressures, will significantly influence the objectives of a planning exercise, decision-making processes and methods used and ultimately the UOW management system that emerges, as has been observed throughout history (Wilson, 2007; Marshall & Farahbakhsh, 2013).

Observation of the broad context of an area being examined is a fundamental activity within IRP (Step 1) to ensure the option responses developed (in IRP Step 3) are appropriate for that context. That is, they provide the necessary service or function and achieve the key articulated planning goals/objectives, as discussed in Section 6.4.

From a water IRP perspective, a lack of appreciation of that broader context can restrict solutions considered and make or break their viability. For example, a study conducted by Turner et al. (2016) identified that Sydney Water provided highly successful water efficiency programs in Sydney, including home audits and retrofits, to over a third of households during the Millennium Drought (over 500,000 houses). Due to the success of the program it was subsequently adopted across much of Australia. However, interestingly, such home audits were rejected as an option in California during their worst drought when they sought advice from Australia, due to the cultural differences associated with the personal safety concerns of householders allowing a contractor into their homes. This nuance in understanding the context is seen repeatedly in water IRP applications (Turner et al., 2010), especially with respect to cultural sensitivity in emerging and developing countries (Turner et al., 2005; White et al., 2011).

With respect to UOW, such social/cultural foundational knowledge and sensitivity is equally important. For example, in Sydney a clear difference can be observed between different areas with respect to volumes of waste produced per dwelling, propensity for recycling and waste management contamination levels (LGNSW, 2019). In addition, in various fora (Turner et al., 2019; Spang et al., 2019), waste management practitioners have voiced their concerns that there is no 'silver bullet' for food waste (and UOW) management, but rather, the need for a mix of solutions tailored for different contexts. This difference particularly true when comparing the metro, regional and rural contexts of Australia.

While practitioners of IRP invariably consider the context in which options and associated decisions are made, there is some room for strengthening the structure of such review. From examination of the theory, sustainability transitions could provide useful additional concepts and methods for such context exploration. This includes the drivers and pressures for change and potential overall vision of a preferred future to strive for while identifying the challenges and opportunities to get there. Sustainability transitions acknowledging the particular importance of innovation, which is especially relevant in resource planning periods of 20 years or so. This innovation factor is becoming even more important to consider in the current rapidly changing socio-technical era.

6.3.1 CASE STUDY EXAMPLES

While all three case studies examined the context of UOW in Sydney, as is commonly conducted as part of IRP Step 1, the use of a Sydney-wide cross-sectoral workshop, Organix19 (Turner et al., 2019), provided a useful overview of the broader context (see Appendix C for the full report). This provided a common view of the current business-as-usual situation, drivers and pressures and overall vision of a circular economy future for organics in Sydney. It also provided invaluable insights from a broad cross-section of participants, highlighting common themes of opportunity and concern as well as nuanced appreciation of specific difficulties that need to be overcome to help UOW transition to a more effective circular economy and sustainable practices.

The Organix19 workshop was conducted in May 2019. It brought together over 65 invite-only stakeholders involved in the generation, management, reuse, regulation and research of UOW management in the greater-Sydney region. While not an exhaustive cross-section of stakeholders, as reflected by the group and acknowledged by the organisers in the report, the group were diverse and able to develop:

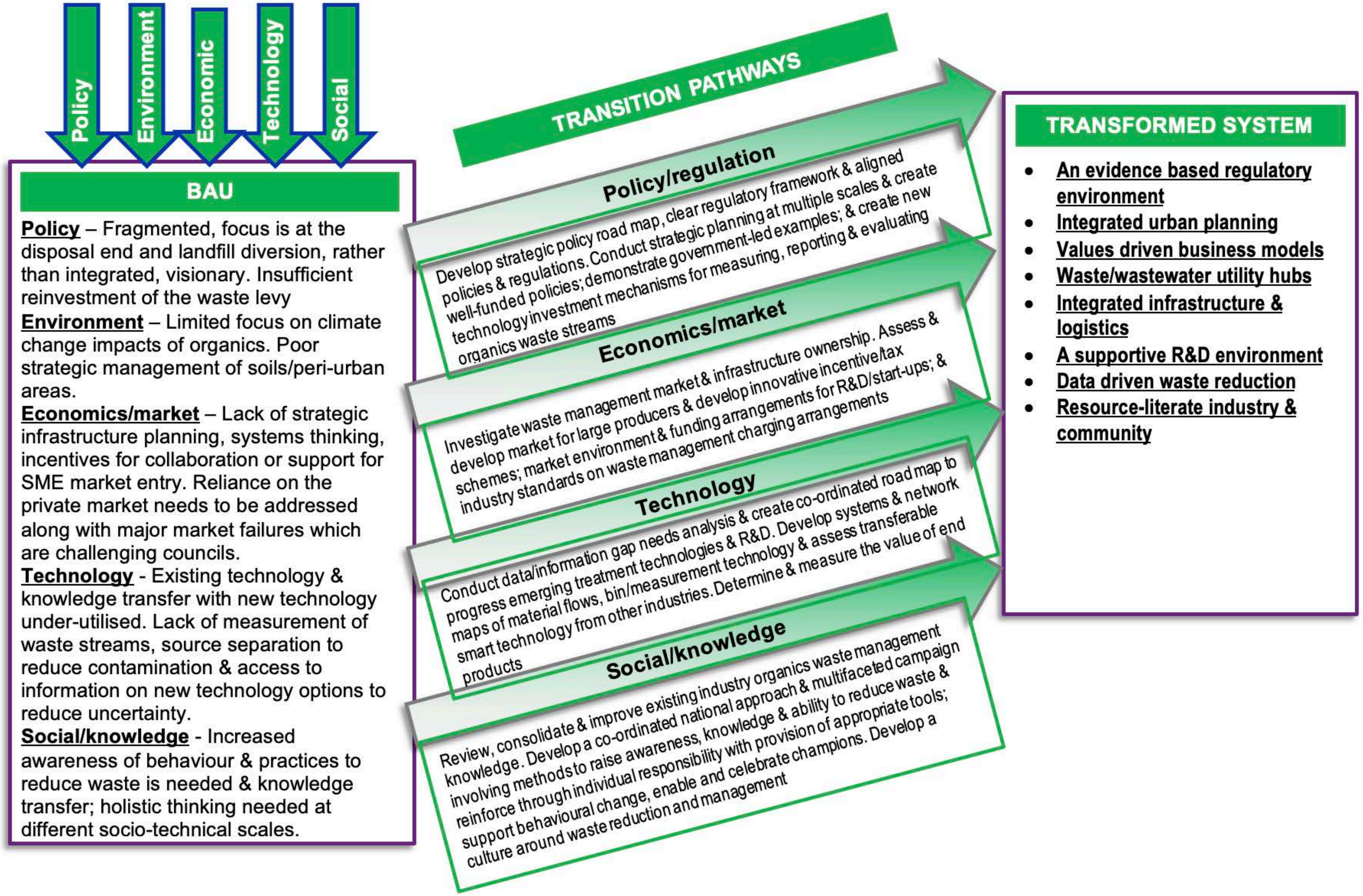
- the current overall system context, including business as usual, drivers for change, opportunities and associated challenges
- a desired vision of a future system embodying circular economy principles
- broad pathways to achieve a transformed system.

A transition management model was used to work through questions and summarise the findings, as shown in Figure 6.5. The model draws on concepts of transition management (Kemp & Rotmans, 2005; Rotmans & Loorbach, 2009) from sustainability transitions as well as economies of increasing returns (Levin et al., 2012). This specific transition model has been used on numerous occasions for stakeholder engagement of complex sustainability problems (Jacobs et al., 2016; 2017; Macintosh et al., 2019).

As a high-level method of inquiry, it was useful in elucidating the features of a collective vision that might be missed during a typical planning process. Table 6.2 summarises the drivers and challenges grouped into emergent themes using a simple political, economic, social, technological, legal and environmental (PESTLE) model. Such a collective vision and categorised themes using a common PESTLE model enabling more clarity on the vision, drivers and challenges and potential high level pathways to transition using an engaging and replicable approach.

The workshop was conducted before the development and release of the 20-year waste strategy in mid-2021. The discussions highlighted numerous cross-sectoral industry concerns such as: the fragmented policy, regulations and management of organics; the lack of systems thinking and strategic planning; and the lack of measurement, knowledge sharing and effective use of innovation, to name but a few. And indeed the desire for organics targets and even banning from landfill as seen in other countries. This shared understanding of the broader context and associated concerns and desires assisted industry dialogue and key stakeholders (such as the NSW Government and Sydney Water) to subsequently include features of the discussions in strategy documents and further investigations. Due to the highly positive feedback, future workshops are planned to help continue the discussions but with an even broader audience.

Figure 6.5 – Transition model developed as part of Organix19



(Source: Turner et al., 2019)

Table 6.2 – Drivers & opportunities for change & key challenges (source Turner et al., 2019)

DRIVERS/OPPORTUNITIES	CHALLENGES
POLICY International, national, state & local policy moving towards halving or banning FW (& in some locations broader organics) from landfill. Circular economy principles incorporated into legislation Local creation of the GSC providing impetus/ opportunity to deal with organics more sustainably	• a lack of an organics ban to landfill or implementation of circular economy objectives, targets & separation requirements • a lack of visionary strategic oversight • insufficient re-investment of the waste levy • policies & regulations are fragmented • a lack of integrated planning at various scales
ENVIRONMENTA L Public concern about climate change, GHG & food security Public realisation that waste is a potential resource	• global concern on climate change is currently focused on more visible waste streams • strategic peri urban land management favours development • the approach to Sydney's resource recovery of organics waste & wastewater is siloed and fragmented
ECONOMICS/MARKET Funding incentives provided by NSW Government are driving interest in organics management market at both large & small scales Interest in using public & private wastewater infrastructure to tap new market opportunities	• a lack of strategically planned waste infrastructure • reliance on the private market • the need for regulatory intervention to help address council challenges • significant market failure in waste management • lack of incentives for collaboration • lack of systems thinking • lack of effective, economical reuse opportunities • significant economic, social and logistical barriers • major urban densification opportunities are being missed • the need to redefine the value of waste beyond economics
TECHNOLOGY New technology driving change especially smaller players/start-ups rather than incumbent providers	• existing organics waste management technology and knowledge is outdated (10-15 years old) • the lack of measurement of various waste streams at source • many current & emerging technology opportunities are not yet being realised • lack of certainty around costs of emerging technologies & local demonstration • source separation to reduce contamination is key
SOCIAL/KNOWLEDGE Increased social consciousness, awareness and desire to recycle stimulated by national media (i.e. War on Waste) & acknowledgement that not one size fits all	• despite increased awareness high volumes of organics waste are produced • awareness on how much food is wasted & desire to engage in change is poor • food waste behaviour is complex & requires a multifaceted approach • to create change there is a need to understand community food waste practices & motivations • need to think more holistically and at different socio-technical scales • need for knowledge transfer of what can be done

6.3.2 BROADER IMPLICATIONS

The collective appreciation of the current situation and future vision together with articulation of drivers, opportunities, challenges and risks from different perspectives is highly useful in planning exercises to help give a mutual picture of the broad context affecting an area being investigated. This especially the case in the initial planning stages of resource management planning exercises, which typically deal with 20 or more year timeframes (Turner et al., 2010). Due to the rapid pace of change in the landscape, regime and niche levels of UOW management, the current window of opportunity and fragmented nature of UOW, using sustainability transitions concepts and methods, and specifically a transition model similar to that used in the Organix19 industry workshop, particularly beneficial.

Incorporating other specific concepts from sustainability transitions (discussed in Section 3.4) within the initial framing/planning step could also provide significant benefit, such as being aware of and specifically bringing to the attention of planners/decision-makers:

- the nuance of landscape drivers in terms of potential system shocks (e.g. China Sword, COVID-19, policy on climate change, mixed waste organic outputs, regulation changes, introduction of organics targets) and varying trends (e.g. population rise, urban densification, growth in the proportion of MUDs)
- windows of opportunity that can assist in accelerating transformative system change if managed through transition management concepts and methods
- future innovation that might cause positive and/or negative disruption to the system
- the risk of LTS lock-in and innovation and adaptive management lock-out
- the stability of the current regime and potential for change, including embedding potential hybrid/distributed socio-technical systems
- the level of uncertainty and opportunity to use scenario planning to deal with various potential shocks and pathways, minimising unintended consequences and maximising adaptation opportunities.

Such sustainability transitions concepts require the development of a structured method to ensure their consideration up front in a planning exercise and an area worthy of detailed investigation and incorporation within IRP.

6.4 CLARIFY THE SERVICE PROVIDED & GOALS/OBJECTIVES

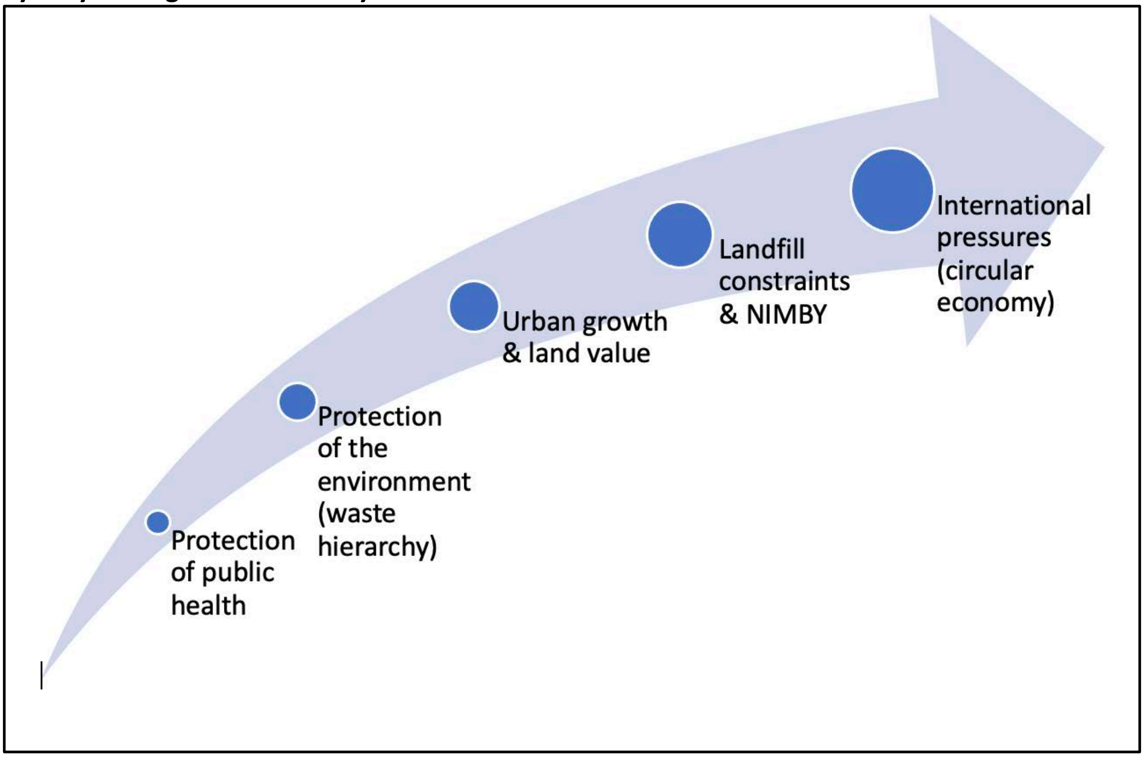
Section 2.5 identifies the need for waste management planning approaches to better consider goals/objectives. This is especially the case for organics, where due to its diverse characteristics goals/objectives have the potential to be numerous and conflicting. However, many of the typical planning and decision-making approaches used in waste are biased. For example, CBA focuses predominantly on prioritising economic objectives (Morrissey & Browne 2004), the waste hierarchy focuses on narrow environmental objectives (Papargyropoulou et al., 2014; Mourad, 2016) and LCA (with LCC) focuses on both environmental and economic objectives (Edwards, 2017). MCDA on the other hand is designed to consider broader economic, social and environmental objectives with associated criteria (Bana E Costa et al., 1997; Morrissey & Browne, 2004) and to help elucidate and consider trade-offs. Hence, as identified in Section 3.5, those decision-making approaches that incorporate MCDA features are beneficial when considering objectives for complex systems such as UOW.

In IRP, asking *what* 'service' is being provided is a fundamental question and key, along with garnering an appreciation of the broader context as discussed in Section 6.3, in helping to develop relevant 'goals/objectives' at the start of a planning process. This focus on service or function and awareness of the environment or context in which the system and subsystems sit is also core to systems thinking and a shared tenet.

From a water IRP perspective, the service is not the water itself but the service it provides, like safe drinking water, clean clothes and attractive gardens (refer to Section 3.2 for further details). Consideration of the service rather than the commodity, water, helps to open the door to both demand and supply-side solutions and find the most appropriate way to fulfil identified service needs and overall goals/objectives. For example, how to best fill the growing gap between hard system supply and soft system demand (i.e. the supply-demand gap), as populations grow, with anything from waterless toilets to desalination plants. This at the lowest cost to society while achieving the highest environmental and societal benefits. Such goals typically result in trade-offs that need to be assessed and balanced. Other goals/objectives, as identified in Turner et al. (2007) for water, may include the need to reduce wastewater passing to sensitive receiving waters, to reduce peak water demand to help optimise assets, to minimise water abstraction energy costs and/or reduce GHG emissions. Or as identified in DECCW (2010) to help provide water supplies for a city such as Sydney whilst also maintaining environmental flows for the health of the river supplying the majority of that water. Such goals/objectives are highly dependent on the system context.

In UOW, the service being provided and thus the goals/objectives of a planning exercise, are, like water, multifaceted. The service and associated goals/objectives are not just about public health and how to remove and process more and more materials generated at the lowest cost but, as discussed in Section 3.2, an ever changing series of services and goals/objectives affected by different drivers and pressures throughout history. Figure 6.6 provides a simplified illustration of the broad eras or waves for Sydney in which these facets have come to the fore, often triggered by voiced public concern (Nicholls, 2002; TEC, n.d.).

Figure 6.6 – Various drivers and pressures affecting key services and goals/objectives in Sydney through recent history



For UOW, the fundamental services centre around amenity and public health: the avoidance and/or removal of a putrescible material to provide clean streets, avoid odours and control vermin and vectors and ultimately minimise health risks. Dial forward to the historical application of the waste hierarchy, and these services have been expanded to fulfil broader environmental objectives. Not merely the removal of putrescible materials and dumping into landfill, but consideration of avoidance followed by reuse and recycling to achieve specified landfill avoidance targets, extend the life of constrained landfills and help reduce environmental impacts. Hence the services of the typical food waste and garden organics generated in the home providing, at the smallest scale, services such as nutritional supplements for animals, organic matter and nutrients to improve garden soils through home composting, increased plant yields and pleasing gardens or even a home cooking supplement through the generation of gas from a home AD plant. The recent advent of the circular economy, has opened up even more objectives by considering organics as a resource and finding higher-order benefits from materials generated (i.e. potential nutrient recovery, energy generation and/or valuable chemical extraction with opportunities for financial returns [Dahiya et al., 2018; Lin et al., 2013]). Broader goals/objectives for UOW are now reflected in the new policies and targets released, including greater emphasis on specific targets for organics (DPIE, 2021a), GHG reduction and net zero emissions (NSW DPIE, 2020b). These latter policies further encourage circular economy outcomes such as energy generation, which have not necessarily been achieved through prior policies that often prioritised composting over AD (refer to Section 1.2). In the face of climate change, resource scarcity/vulnerability and population growth, even more emphasis will likely be put on goals/objectives that focus on food security and resource-input efficiency and output generation/use in the future.

When considering UOW, still missing when setting goals/objectives, are the interconnects (and associated potential opportunities, impacts and trade-offs) between different sectors (i.e. wastewater, agriculture and energy). Such disparate sectors will typically prioritise one goal/objective over another (i.e. nutrient capture/recovery versus energy generation). As indicated in Section 2.5, current waste management decision-making approaches fall short on considering economic, social and environmental objectives. Hence, when broadening the boundary of organics decision-making to streams beyond residential food waste and garden organics, which encapsulate new cross-sectoral interconnections and stakeholders with different priorities (as noted by Mourad [2016] for food waste), the array of services, goals/objectives and trade-offs need to be expanded.

Sections 6.1 and 6.2 identify the need to carefully consider the system(s) and boundaries together with stakeholders involved in an UOW planning exercise and Section 6.3 highlights the need to garner an appreciation of the broad context. Here using that information the importance of clarifying the services and associated goals/objectives of UOW are identified together with potential cross sectoral opportunities, negative impacts and trade-offs. Whilst there are many examples of IRP helping to work through and elucidate such system characteristics there is an opportunity to strengthen the decision-making process with well established MCDA approaches during the framing/planning stage.

6.4.1 CASE STUDY SYNTHESIS

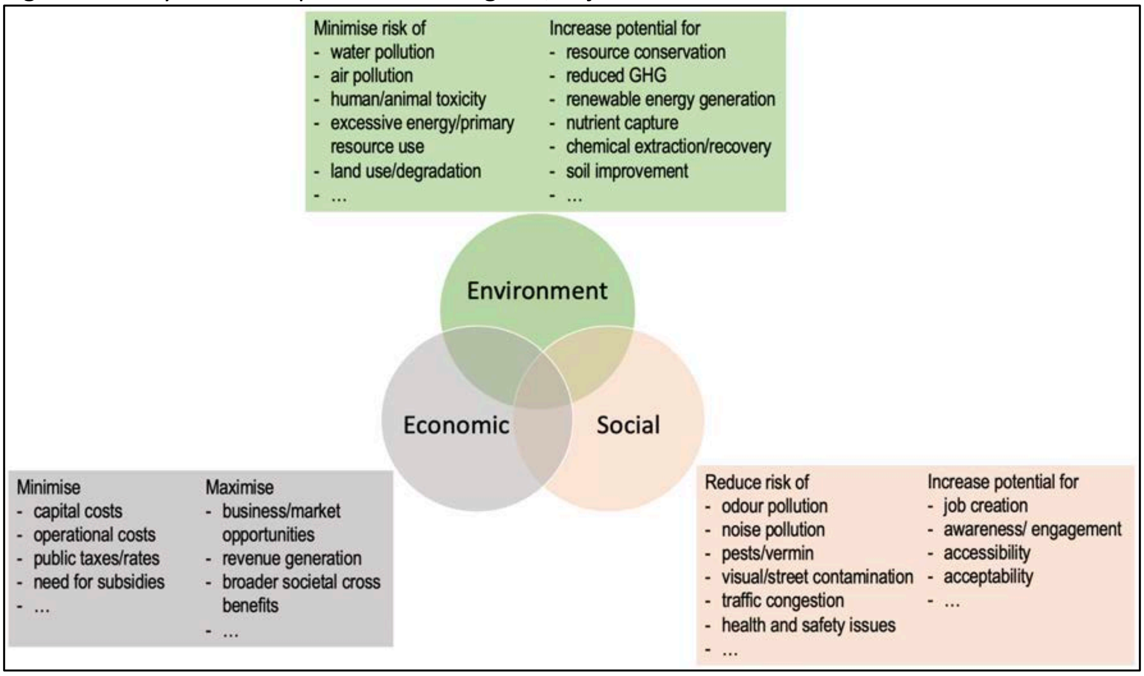
None of the case studies were conducted at the start of a strategic planning process or as part of an IRP exercise. Hence, they did not have the opportunity to fully explore with stakeholders the framing of the services being provided or the goals/objectives or more detailed criteria for such planning.

As discussed in Section 6.2, in the PUP case study semi-structured interviews were conducted. The interviews included asking stakeholders questions about their motivations for using innovative UOW management solutions. The motivations illustrated in Figure 6.4, although only providing a partial view of potential objectives, identified a range of economic/financial, social and environmental motivations which could inform UOW goal/objective setting. Such goals including for example reducing waste to landfill, costs, smell/vermin impacts and traffic congestion as well as improving resource recovery and environmental outcomes and capturing opportunities associated with energy generation and new business.

In the IWC case study, as discussed in Section 5.0, the research was initially meant to be a public document and assist the council in identifying potential UOW solutions to aid them in achieving their overarching goal of being "a zero waste community" in accordance with the community strategic plan (IWC, 2018, p.17). However, due to changes in council executive staff and direction the project became an illustrative internal document. As part of the lead up to the options workshop in the project, goals/objectives were drawn from the community strategic plan to help assess which kinds of options might help achieve existing articulated goals/objectives. These goals/objectives were difficult to interpret and somewhat lacking in the specific objectives for waste management or more specific UOW as the more detailed waste management plan had not been developed at that stage. The community plan did however highlight a number of potential useful related goals/objectives, including for example "a zero waste community with an active share economy", …."zero emissions community that generates and owns clean energy"…"manage finite resources in the best interest of current and future communities". Such goals illustrating the cross sectoral and broad sustainability goals/objectives likely required for UOW management planning.

Figure 6.7 illustrates a synthesis of generic UOW goals/objectives that emerged from the case study investigations and examples found in the literature. Many of these goals/objectives would be relevant to most urban environments. However again the services, goals/objectives and associated detailed criteria and their careful delineation need to be assessed for each jurisdiction.

Figure 6.7 – Synthesis of potential UOW goals/objectives



(Adapted from Iacovidou & Voulvoulis, 2018)

Despite a lack of clear goals/objectives both the PUP and IWC case studies also explored more detailed criteria when illustrative options were discussed with the various stakeholders involved in workshops. These more detailed potential criteria are discussed in Section 8.0.

6.4.2 BROADER IMPLICATIONS

While there was limited opportunity to explore the UOW goals/objectives for each of the case studies upfront, they along with examples from the literature help identify some of the general core goals/objectives that need to be considered for UOW. Looking across the case studies and literature it is clear that the service goals/objectives and more detailed criteria are generally not extensively considered for broad UOW planning and decision-making in Australia. This is due in part to its fragmented management, the power of the private sector, and, until recently, the dominance of the narrow waste hierarchy as a guide.

The process of objectives setting could be significantly strengthened for UOW by the MCDA branch of systems thinking that incorporates problem-structuring methods (Belton & Stewart, 2002) and value-focused thinking (Keeney, 1992). Keeney and McDaniels' (1999) study of the energy sector provides one of the few examples of value-focused thinking used specifically in IRP, highlighting the opportunity for further targeted MCDA-related research.

Indeed, as the goals/objectives need to be considered up front in IRP Step 1, and, importantly, reassessed during the more detailed analysis stages of a planning exercise (i.e. IRP Steps 2 and 3), there is an opportunity to go further by exploring 'value-context-alternatives focused thinking', which as discussed in Section 2.3.6 builds on Corner et al. (2001). Revisiting the initial goals/objectives through iteration between value-context-alternatives focused thinking helps expose the nuances at a jurisdictional level. While IRP does consider core goals/objectives upfront as a matter of course within IRP Step 1, and again during Steps 2 and 3, it would benefit from the rigour of MCDA problem-structuring methods and specifically value-focused thinking, and thus warrants further investigation.

This Section has explored how considering the system and boundary of analysis along with the stakeholders directly and indirectly involved as well as the key services, objectives and broad context are necessary when framing an UOW planning exercises. The next Section looks at how resource disaggregation, forecasting, and mapping and visualisation (IRP Step 2) can assist in unveiling the detailed context of UOW generation and management to aid in planning, analysis and decision-making.

7 ANALYSING THE CONTEXTUAL DETAIL (IRP STEP 2)

This Section focuses on the gaps and opportunities raised in Section 2.0 relating to the need to better consider the detailed context of a jurisdiction undergoing a planning exercise. Specifically, it considers how IRP (Step 2) can assist in filling those gaps and opportunities for UOW by:

- disaggregating the resource
- forecasting
- mapping and visualisation.

Resource disaggregation and forecasting are both conceptual and methodological strengths of IRP. In contrast, mapping and visualisation is a method not historically used in water IRP. It has been used here in the Sydney-based case studies, along with resource disaggregation and forecasting, to test its application in UOW. All three methods show promise but also some limitations, as illustrated through the case studies and discussed below.

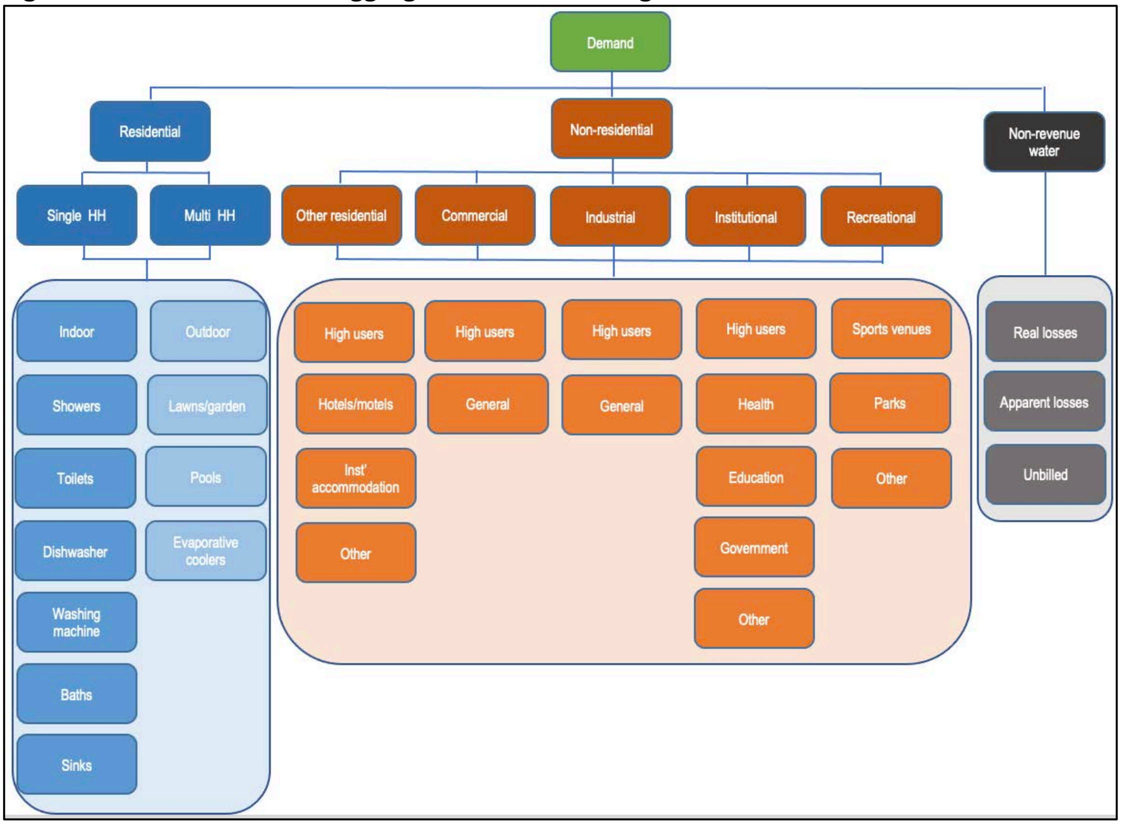
7.1 DISAGGREGATING THE RESOURCE

Section 2.5 identifies the need to move away from the 'silver bullet' thinking of LTS and towards a more nuanced response to specific contexts, utilising a network of complementary solutions. To help achieve this, both a broader socio-technical systems perspective and sufficient contextual detail in a jurisdiction are needed to inform planning, despite data gaps. These insights were raised by Spang et al. (2019) for food waste. Such insights are even more pertinent when considering broader UOW. This is particularly the case in Australia due to its highly fragmented management of UOW and significant gaps in data, especially in the non-residential sector, and new national and state level policy and targets concentrating specifically on 'organic' waste.

The detailed investigation and disaggregation of a resource is fundamental in IRP (Step 2) and commonly practiced at various levels, depending on the purpose of the analysis and data available. Such detailed investigations are in line with systems thinking tenets, where systems are conceptualised as disaggregated 'closed' and 'open' systems, sub-systems and components, interacting with other systems to varying extents (refer to Section 3.3).

In water IRP, systems are observed through the 'service' they provide and by the disaggregation of the 'use' of water from both a holistic top-down and more detailed bottom-up socio-technical perspective. This enables the efficiency or conservation potential to become more evident. Such disaggregation traditionally centres around daily bulk water metered usage, providing a top-down overview. In the Australian context, where universal metering has been a feature since the early 1990s, the bulk water view is combined with analysis of customer water meter readings held in utility or council databases, which are typically read on a quarterly or monthly basis for residential and non-residential customers respectively. The databases are specifically designed to charge customers for their water usage through user-pays pricing principles, not to examine demand but adapted to do so. Databases vary considerably across jurisdictions but can often be disaggregated into typical sectors and sub-sectors, as illustrated in Figure 7.1.

Figure 7.1 Illustration of disaggregation of water usage in IRP



(Adapted from ISF, 2011)

With specific research, such as end-use studies and surveys (Beal & Stewart, 2014) the residential sector can be broken down further into individual socio-technical end uses/micro components such as toilet or shower usage, also shown in Figure 7.1. Individual building audits, and now more recently smart water meter analysis, can help provide a more detailed understanding of demand in the non-residential sectors and sub-sectors. However, this is typically not at the end use/micro component level due to the sectors' more difficult heterogeneous characteristics.

Such top-down and bottom-up analysis and modelling has been conducted in water IRP in Australia since the 1990s (White, 1998; White et al., 2003). Hence, there is considerable experience in collecting and analysing such data in Australia. Significant advances occurred during the Millennium Drought (Turner et al., 2016), and again more recently, due to advances in smart metering and machine learning (Stewart et al., 2018). Although, they have taken years to adopt since first trialled at scale in the mid-2000s (Turner et al., 2010b). Advances in technology, such as smart meters, provide more granular and sometimes real-time data, which helps to develop an even more detailed understanding of individual customer demand (Turner, 2015; Stewart et al., 2018). This includes greater appreciation of temporal use and seasonal variation (i.e. summer versus winter garden watering), which can have significant implications on service infrastructure capacity and operation. In addition, advances in the techniques used for surveys (including on-line surveys) have helped to improve and reduce the costs of other forms of data collection and analysis, especially those relating to behaviour within households (Diringer et al., 2018; Turner et al., 2010a). All these advances help to improve both demand forecasting and the design, costing and implementation of demand-side solutions.

In UOW, such disaggregation of the various streams of organics and their wastage is more difficult to achieve due to the fragmented management and lack of basic measurement of UOW or associated volumetric (preferably weight) user-pays pricing for individual customers. Residential customers are typically only charged a flat rate for annual bin service through their rates bills, whether bins are presented at the kerb each week or not, or full or not. For non-residential properties, the waste management contractors typically remove a certain number of bins per week (or other agreed schedule), which again are not charged by weight except in cases where customers pay additional fees if over an agreed weight limit. Hence, to form a disaggregated picture of UOW generated by sector, sub-sector or more detailed end use/micro component, analysis is more difficult and relies on what data estimates and limited measurement studies are available, with many studies not in the public domain. This lack of transparency restricts knowledge sharing and increases the risk of unnecessary duplication of research and analysis needed to gain a more holistic, yet detailed, picture of UOW and fill the acknowledged data gaps.

Even with significant data gaps, the IRP methods of inquiry have been used to build a picture of a resource. This was the case for water in developed countries such as the US and Australia in the 1980s and 1990s (White, 1998), when little data, including metered data, was available. It was also the case in the 2000s in developing countries such as Egypt and Oman (Turner et al., 2005; White et al., 2011), when an array of methods were used to substitute for the lack of metered data or even basic appreciation of how water was used. Hence, it is possible to adapt the IRP sector, sub-sector and end use/micro component disaggregation methods to build a more fulsome appreciation of UOW to assist in more informed planning, analysis and decision-making. It is also possible to gradually build on this picture through targeted collection, collation and analysis of data as conducted in the water sector over many years.

7.1.1 CASE STUDY EXAMPLES

Two useful IRP disaggregation methods were applied in the UOW case studies:

- pooling disparate datasets to provide a holistic and disaggregated view of UOW
- garnering snapshot insights attained from analysis of that data.

These are discussed below, drawing from the experience of the case studies.

7.1.1.1 POOLING DISPARATE DATASETS

All three case studies demonstrate the collection and analysis of disparate sets of data to help achieve a more detailed understanding of organic waste generation in the residential and non-residential sectors and sub-sectors. This was done for the various streams of UOW within distinct boundaries of analysis (i.e. building/precinct, sub-LGA, LGA). Such holistic yet detailed disaggregated analysis of waste generation is not currently performed for broad UOW in Australia and the pooling of datasets across disparate sources and industry sectors is limited. Hence, the data-pooling methods applied in the case studies were novel. Key disparate datasets used in the case study analysis are summarised in Table 7.1 and data challenges are summarised thereafter. Significantly, only a few of these datasets are currently publicly available.

Table 7.1 – Examples of types of data available, collated and analysed in the case studies

Type	Source	Comments	PUP	CP	IWC
Residential					
Population & dwelling nos.	Australian Bureau of Statistics (idprofile) Census records (5 yearly – 2011, 2016)				
	Property manager records				
Aggregated household waste streams (HHs)	NSW Environmental Protection Authority Local government WARR data reports (Annual – 2005-06 to 2018-19)	Estimates for food waste, garden organics, food organics, garden organics (T/a and kg/p/a or kg/hh/a)			
Household waste audits (SDs, MUDs)	A Prince Consulting (individual/SSROC) Council Kerbside Waste Audits (1999, 2001, 2005, 2008, 2011, 2015, 2019)	Estimates for food waste, garden organics, food organics garden organics (kg/hh/a)			
High-rise waste audits (HR MUDs)	A Prince Consulting (individual/SSROC) Council Kerbside Waste Audits (2019)	Estimates for food waste, garden organics, food organics garden organics (kg/hh/a)			
Used cooking oil	Literature				
Property wastewater discharge	Sydney Water Water meter/wastewater discharge factors database				
	Private utility				
Non-residential					
Business nos. by type	Australian Tax Office (idprofile) Council ATO records				
Business waste audits	NSW Environmental Protection Authority Bin Trim audit records	Estimates of food waste, garden organics (kg/prop/a)			
Business waste records	Property manager records/bills	Estimates of waste (kg/prop/a)			
Business waste measured	Property manager records	Food waste measured (kg/prop/wk)			
Garden organics	Contractor	Estimate garden organics (bins/prop/wk)			
Used cooking oil	Contractor	Used cooking oil measured (kg/prop/wk)			
	Literature				
Wastewater discharge	Sydney Water Water meter/wastewater discharge factors database				
	Private utility				
Fats oils and grease	Sydney Water grease trap data on volumes and recommended collection frequency data base	Fats oils and grease (kg/prop/a)			
	Contractor	Fats oils and grease (kg/prop/a)			
Other waste	Literature	Animal waste (kg/animal/a)			

Notes: CP - Central Park, PUP - Pyrmont Ultimo and IWC - Inner West Council
Green represents data used in a case study, amber partially used and white not at all.

Data challenges included the following:

Availability

- The data required to estimate volumes/mass of UOW was spread across various stakeholders and sources such as Sydney Water, the NSW Government, councils, the Australian Bureau of Statistics (ABS) and waste management contractors.
- In many cases, data was in a raw format within a database and required extraction and/or manipulation assistance from the stakeholders in possession of that data.
- Due to a lack of knowledge sharing within the waste industry, some data was simply not accessible.

Privacy

- Some data was commercial in confidence or did not appear to exist (e.g. non-residential waste at the sub-sector level).
- Participants in some studies only agreed to participate if study reports were kept confidential.
- Particular databases were subject to privacy agreements.
- Some data was aggregated to a minimum number of properties, when geospatially mapped, in order to protect individual property details.

Quality

- Classification of premises under the Australian and New Zealand Standard Industrial Classification (ANZSIC) codes held within industry databases is somewhat subjective in the non-residential sector, resulting in inconsistencies in interpretation. In some cases, stakeholders involved in such databases advised that these codes are not kept up to date, especially in commercial units that are multi-functional and can change tenancy frequently.
- Obvious data entry errors were present in datasets, requiring parts of the data to be excluded.
- Some datasets were so small their use for generalisation or extrapolation was limited.
- In some reports, the assumptions and statistical analysis of datasets was ambiguous and potentially flawed, making it difficult to use the data and results effectively.

Many of the data challenges identified are shared with the water/wastewater industry.

The CP case study provides an example of the disparate sets of data pooled for just one building/precinct in Sydney. The data is the first publicly available example in Sydney, despite similar developments now being a core and ongoing component of the NSW Government housing expansion plans for the city (refer to Section 4.2). Table 7.2 illustrates the volumes of organic and organic-rich waste collated through various sources, ranging from measured to estimated. In all cases, I was the researcher drawing from individual organisations and datasets. This took considerable time due to various barriers, which often centred around stakeholders finding time to access and collate datasets within their own fragmented records while conducting their normal daily management tasks.

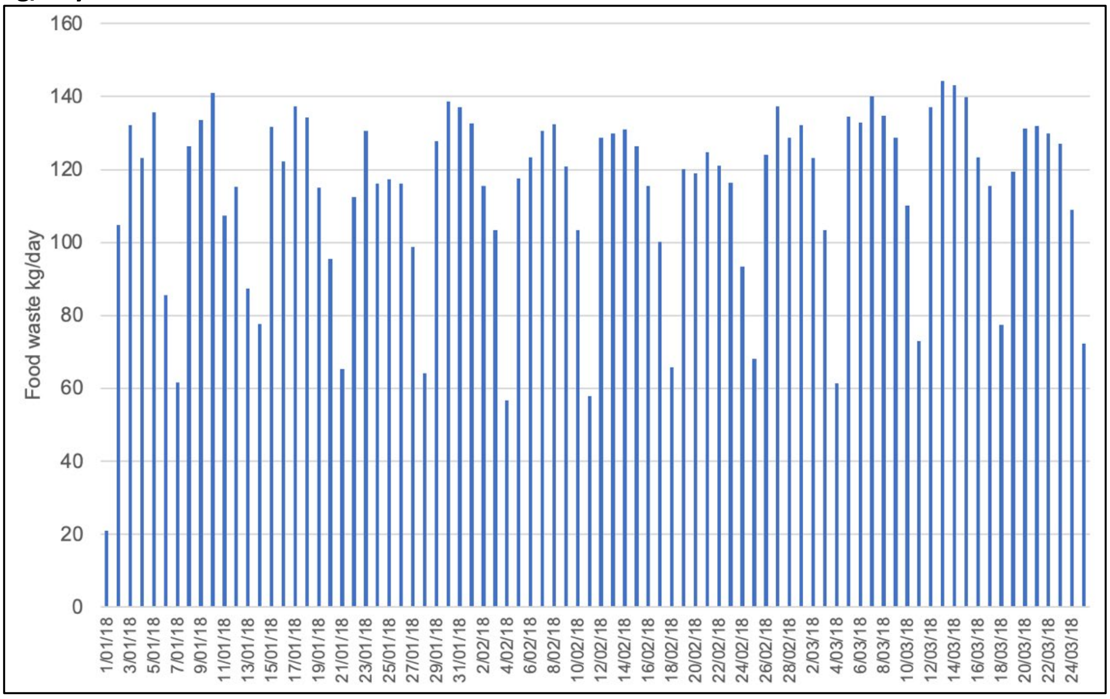
Table 7.2 - One Central Park organic waste streams in 2017

Waste stream	kL/a	Comments
Residential		
Municipal Solid Waste	3,351	Approx. estimate of total volume of 240 L & 660 L red bins collected in 2017 (i.e. volume of actual waste will be less) >Building manager bin collection records
Commercial/retail		
Food Waste		Retail food waste within red bin commercial solid waste figure below (except for recent trial commencing mid December 2017).
Commercial Solid Waste	4,106	Approx. estimate of total volume of 660 L red bins collected over 2017 (i.e. volume of actual waste will be less)* >Building manager & waste contractor bin collection records
Supermarket		
Food Waste (Oz Harvest)		Data not provided
Unavoidable Food Waste (EarthPower)	194	Approx. estimate of total volume of 240 L and 660 L bins removed in 2017 (i.e. volume of actual food waste will be less) >Building manager & waste contractor bin collection records
Commercial Solid Waste	882	Approx. estimate of total volume of 1,100 L and 240 L (organics contaminated) bins removed in 2017 (i.e. volume of actual waste will be less) >Building manager & waste contractor bin collection records
Used Cooking Oil	12	Approx. 1,000 L collected every month (actual volumes per month recorded) >Waste contractor records
Fats Oils & Grease	300	Approx. 3 x 15,000 L and 1 x 5,000 L collected from the grease trap tanks every 2 months. Figure includes total volume removed (i.e. concentrated fats, oils and grease, water and food waste detritus caught in the system) >Building manager & waste contractor bin collection records + industry advisor
Wastewater System		
Wastewater (discharged/ diverted)	62,050	Currently approx. 75% of wastewater is treated through the on-site water recycling plant (i.e. 500 kL/day treated & & 170 kL/day discharged/diverted). Excess wastewater discharged to sewer will decrease in future when the plant is fully operational & treating greater levels of wastewater for recycled water end uses at the completed Central Park development & new UTS building opposite. >Recycled wastewater treatment plant manager records
Trade Waste (sludge discharged)	4,380	Approx. estimate of 12 kL/day of sludge is discharged to the sewer. This volume is likely to increase in future when the plant is fully operational. >Recycled wastewater treatment plant manager records
Garden Organics		
Garden Organics	333	Approx. estimate of 35 x 240 L & 4 x 1,100 L bins collected every 2 weeks (i.e. volume of actual waste will be less) >Garden organics/horticultural maintenance contractor bin collection estimates

(Adapted from Turner et al., 2018)

An example of a rare dataset obtained and identified in Table 7.1 and Table 7.2 was the food waste generated by the commercial retailers. This data was obtained by the building manager during a three-month food waste measurement trial specifically set up for the case study. The collection and measurement of food waste for each individual food outlet was conducted daily by the cleaning contractors for the building, supported by the waste management contractor. Of the 50 retail outlets in the building, 22 of the 27 food outlets participated in the trial. Based on the average of the three-month trial, over 800 kg/week (extrapolated to 42 t/a) of food waste was generated just from kitchen waste. Figure 7.2 illustrates the relative consistent weekly pattern observed in the waste collected, with the least amount of food waste generated on Sundays and most during the middle of the week. With the university campus located directly opposite One Central Park, it would be expected that academic terms and holiday periods influence the volume of food waste collected over the period assessed. In March, when the autumn semester commenced, there was approximately a 10% increase in food waste collected compared to the January and February periods. Thus illustrating food waste generation can be significantly affected by its context.

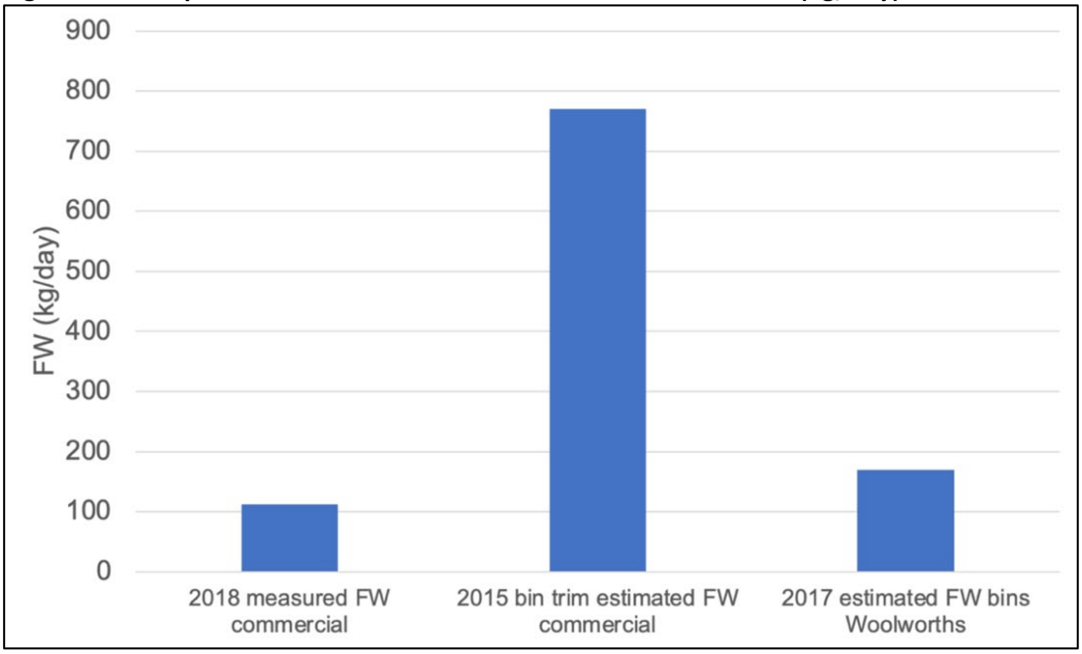
Figure 7.2 - Measured food waste from participating retail kitchens at One Central Park kg/day



(Source: Turner et al., 2018)

Figure 7.3 compares this measured data to a 2015 'Bin Trim' audit for the building, and an estimate of food waste collected separately from the Woolworths grocery retail outlet in 2016–2017. The difference between the 2015 audit and 2018 measured figures are significant and illustrate the value of actual measured data to enable a comparison with cheaper but less reliable visual audits. The difference observed could be associated with various issues: an over estimation of waste in the visual inspection technique used and associated conversion of volumes to weights in the Bin Trim audit, the inclusion of additional waste in communal food court bins in the Bin Trim audit, visiting a proportion of different retailers in 2015 compared to 2018, the 2015 audit and advice obtaining the desired effect of reducing wastage for those still trading in 2018, and the 2018 measurement trial causing an effect on food waste generated (i.e. the Hawthorne effect).

Figure 7.3 Comparison of measured versus estimated food waste (kg/day)

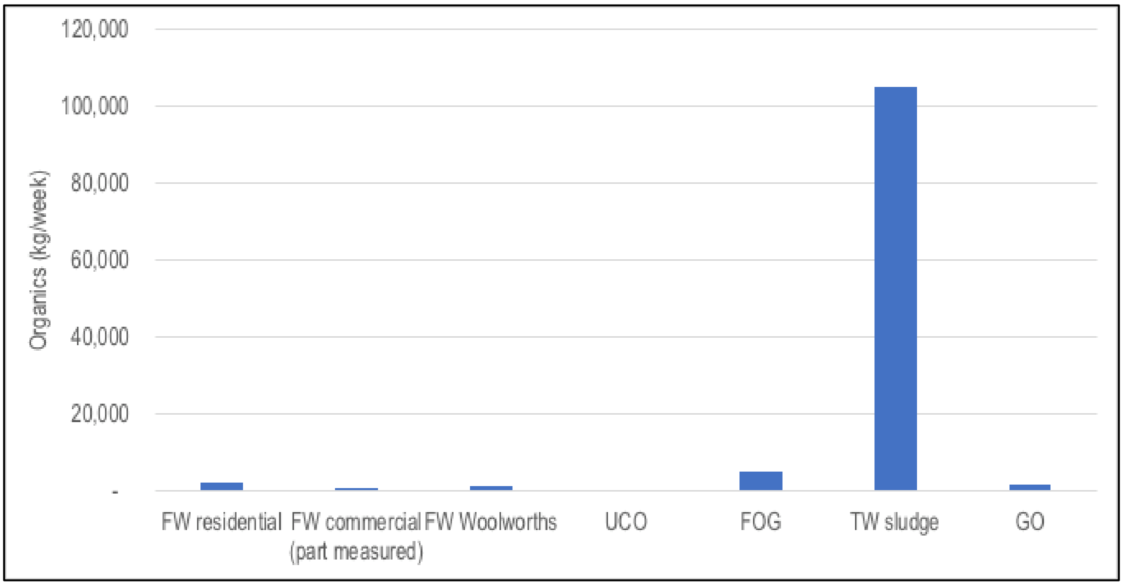


(Source: Turner et al., 2018)

Another rare dataset collated to garner a more holistic picture of the organics generated in the building was on the used cooking oil obtained from the waste management contractor. Used cooking oil is typically collected in a closed communal receiving vessel near other waste collection areas in such large buildings. This service (and collection) was provided for free in this particular case due to the quantity available to the contractor and its intrinsic value. This is often not the case where there are smaller quantities to collect or in regional settings due to logistics and transport costs. The used cooking oil from the retailers within the building ranged from 600 to over 1,200 L/month from the 2016–17 records, with an average of 1,000 L/month (Turner et al., 2018).

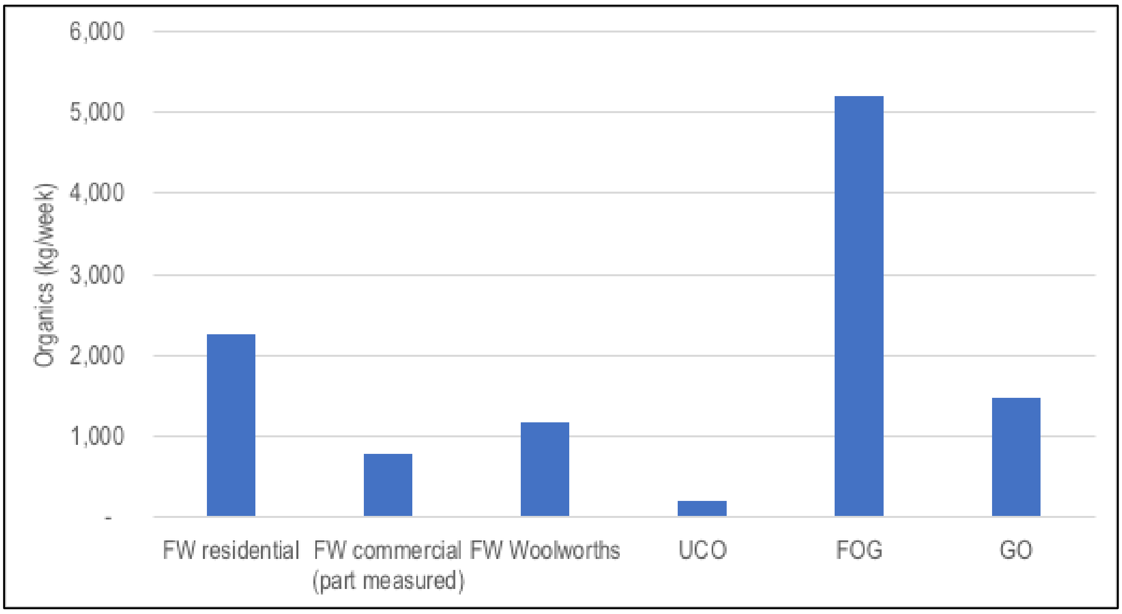
Figure 7.4 (a) all streams and (b) excluding trade waste sludge, shows the different organic streams pooled from the various sources identified in Table 7.2, converted to kg/week. Again, this is one of the few publicly available sources of combined data for such high-rise, dense urban developments in Sydney (and potentially Australia) and illustrates the significant variation between the different streams. The large quantity of trade waste sludge was generated from an on-site wastewater recycling plant, located in the basement of the building. Although such on-site plants are still relatively unusual at the building scale in Australia (White et al., 2018) the basement plant room provides an ideal location to co-locate a potential retrofitted on-site AD plant for organics management.

Figure 7.4 - Collated organic waste streams in kg/week
(a) All streams



(Source: Turner et al., 2018)

(b) Excluding trade waste sludge



(Source: Turner et al., 2018)

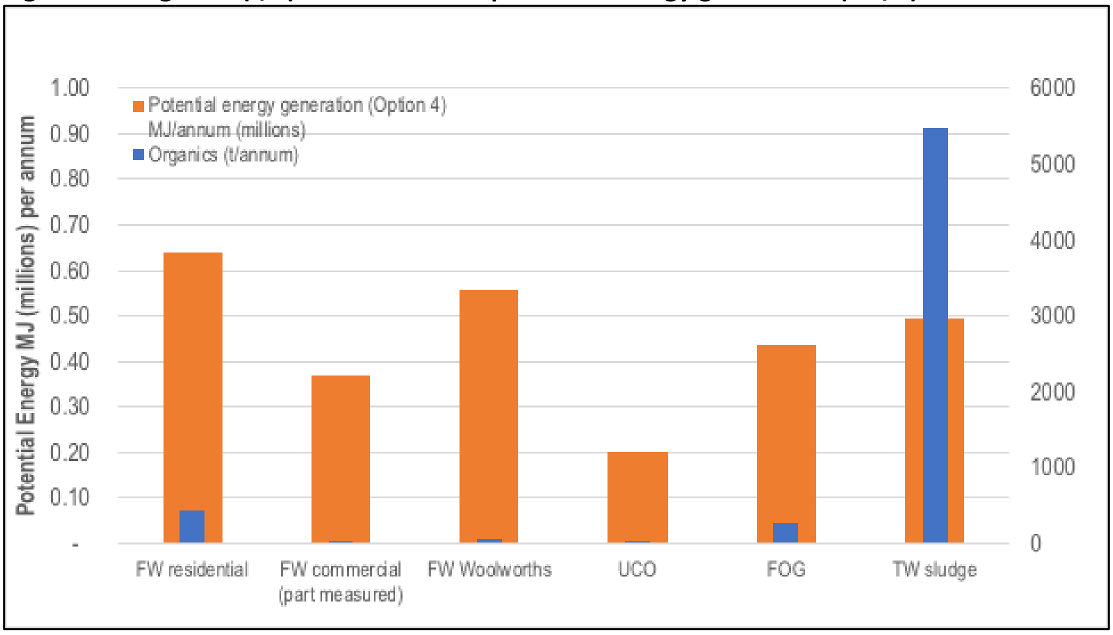
7.1.1.2 GARNERING SNAPSHOT INSIGHTS

Building on the examples of collating disparate datasets, the case studies also illustrate the potential to garner snapshot insights into the organics being generated. Each case study shows an example at a different scale. The case studies also illustrate how the combination of a more holistic and disaggregated view of UOW, as advocated by systems thinking and practiced in IRP, can assist in informing the development of context specific options (IRP Step 3). These particular attributes a nuance of IRP not clearly articulated in other planning and decision-making approaches and a key strength of IRP.

As identified earlier in the CP case study, disparate datasets with varying levels of reliability (see Tables 7.1 and 7.2) were used to obtain a disaggregated estimate of the various types of organics at the building/precinct scale, a rare data set in Australia. As shown in Figure 7.4a, this indicated which streams were generating the most organic waste within the development; in this case the sludge from the wastewater recycling plant dominated the organic flows.

These investigations enabled an estimation of the bioenergy potential, as shown in Figure 7.5. Various options were considered (i.e. from full to partial recovery of each UOW resource stream dependent on assumed collection methods). This allowed a preliminary estimate of the size and feasibility of on-site AD (and associated costs and benefits) before a more detailed feasibility assessment. Figure 7.5 illustrates that, despite the food waste, used cooking oils and fats, oils and grease streams being significantly less than wastewater sludge, their bioenergy potential is far greater. Consideration of bioenergy potential is an essential first step in assessing the sizing and viability of novel on-site technology. Such collective detailed knowledge of UOW at the building/precinct scale is typically not known and thus opportunities to manage organic resources using innovative on-site approaches are often overlooked, despite their potential.

Figure 7.5 Organics (t/a) and associated potential energy generation (MJ/a)

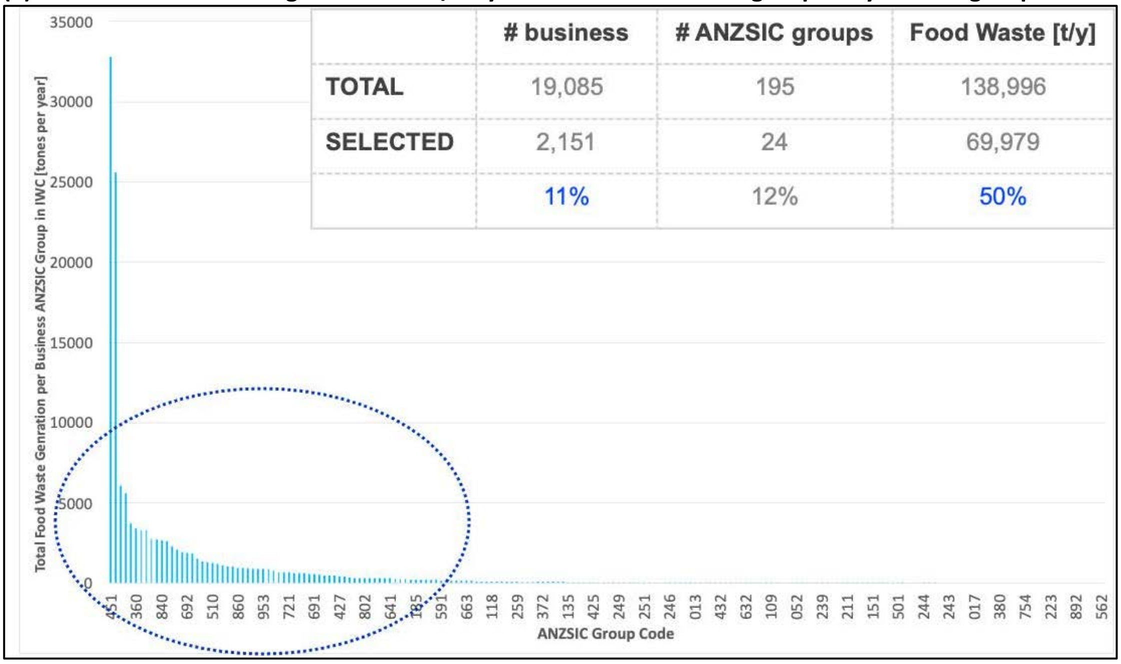


(Source: Turner et al. 2018)

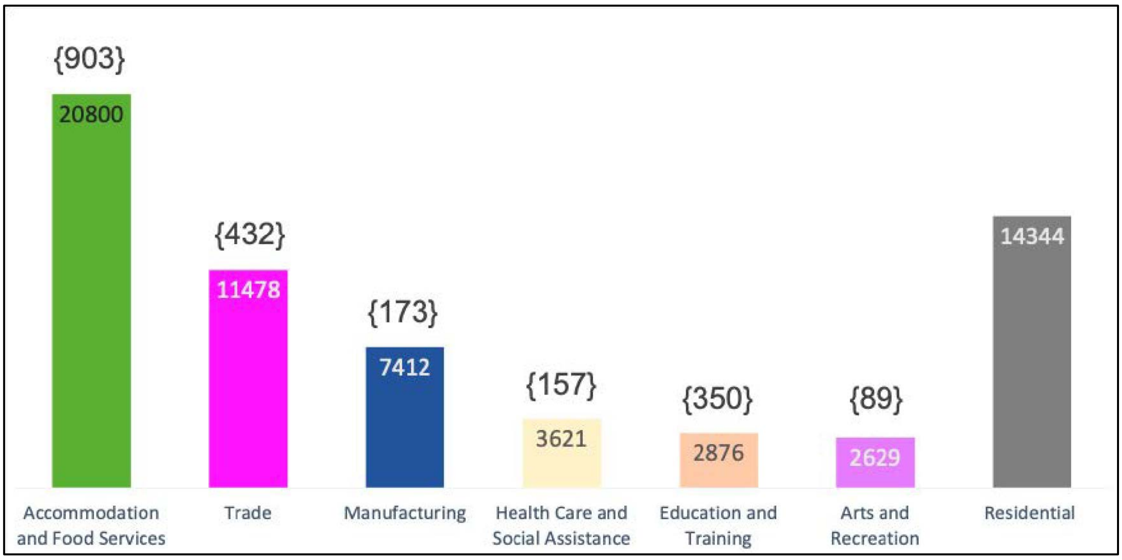
In the IWC case study, a combined and disaggregated picture of residential and non-residential organics was constructed. This time however, for the whole LGA. This was, again, a first at this level of disaggregation. For the non-residential food waste the disaggregated data was obtained from various sources including the Australian Tax Office business records and Bin Trim audits (see Table 7.1). IWC-specific Bin Trim audits in the area were used as well as Sydney-wide equivalent Bin Trim audits for each ANZSIC group. The analysis enabled an overall and specific group disaggregated estimate of non-residential food waste for the IWC LGA. By subsequently focusing on the highest estimated generators of food waste by group, core sub-sectors were identified (i.e. accommodation and food services). Around the top 10% of ANZSIC group businesses were estimated to be responsible for 50% of the local food waste generated (refer to Figure 7.6). These kinds of estimates are invaluable when deciding where to focus and how to develop options (i.e. IRP Step 3).

Figure 7.6 - Non-residential food waste estimated in t/a

(a) Estimated food waste generated in t/a by businesses in the IWC grouped by ANZSIC group codes



(b) Top six ANZSIC divisions generating food waste in IWC in t/a



{ } represents number of businesses

(Source: Jazbec et al., 2020a. Reproduced with permission of authors and client)

7.1.2 BROADER IMPLICATIONS

There is currently significant paucity of UOW data for analysis, especially in the non-residential sector, and there is industry recognition that this gap needs to be filled for Sydney and Australia more broadly. Such data paucity is also considered a global issue for food waste by Spang et al. (2019). While there are significant data gaps, some are being filled for Sydney by targeted research to find ways to pool UOW data (Jazbec et al., 2023), directly influenced by the case studies that have applied the methods described. Additional research is filling gaps for food waste at a national level (Arcadis, 2019; FIAL, 2021). However, more co-ordinated research and collaboration are needed, and government leadership in the form of law enforcer to mediator is required, as advocated by transitions management (Rotmans et al., 2001).

Concerted effort is needed for industry sectors to work together to improve waste measurement and data transparency, quality and accessibility. Such gradual improvements in data have been achieved for food waste in countries such as the UK, which is now seen as a leader in how to tackle food waste issues, with several countries, including Australia and New Zealand using many of the programs as a template (UK WRAP, n.d.). UOW requires even more concerted effort. While measurement and data improvements are gradually made in Australia, the collation of disparate datasets, as illustrated by the case studies, will be needed.

Co-ordination and crosschecking of disparate datasets (i.e. Sydney Water, NSW EPA, NSW Food Authority[19], Food Regulation Partnership[20] and councils) provide an opportunity to pool the currently available data. Shared data collection, databases and analysis as well as crosschecking and revision of ANZSIC code categories for sub-sectors and individual businesses provides the opportunity for further improvements. Also, particular groups such as building managers (co-ordinated through their retail association) could rapidly measure and collate data on organics on their sites, as illustrated in the CP case study, and provide such data to a centralised co-ordinating body such as their local council and/or NSW EPA.

To achieve emerging targets by 2030 in NSW, such as halving food waste, halving organics sent to landfill and net zero emissions from organics waste, there needs to be greater appreciation of where and how UOW is being generated. Having a clearer and more detailed disaggregated picture of the various organics streams provides the opportunity to manage UOW more effectively.

While disaggregating UOW streams is different from disaggregating water demand, IRP concepts and methods can assist in helping to improve both the holistic and disaggregated view of UOW. The case studies illustrate this and importantly, do so by pooling the limited data available. Such pragmatic pooling of data (and clear identification of the gaps that need to

[19] https://www.foodauthority.nsw.gov.au/help/licensing

[20] https://www.foodauthority.nsw.gov.au/retail/inspections

be filled going forward) will be key while efforts are made to gradually advance UOW measurement, analysis and reporting. This assisting the emerging UOW sector to harness the potential of demand-side opportunities over time, similar to that achieved by the water industry.

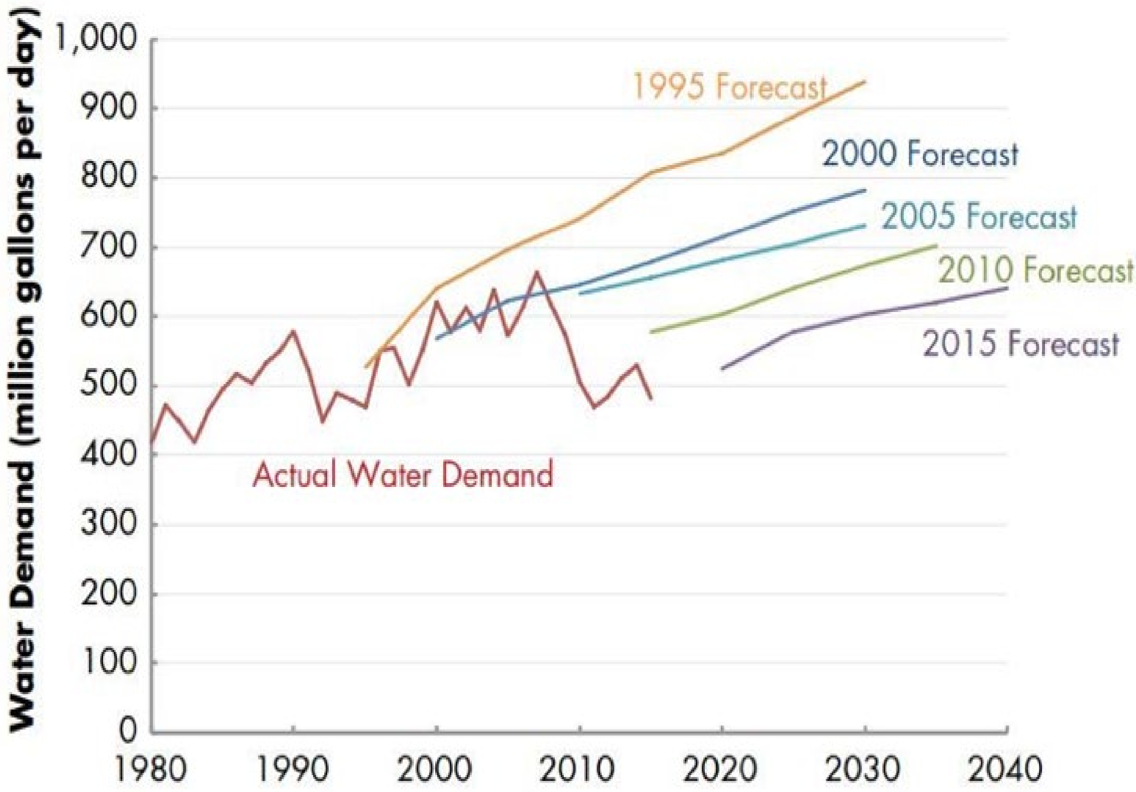
7.2 FORECASTING THE RESOURCE

Another aspect of understanding the detailed UOW management context of any given region is to be able to forecast the organic (waste) resource generated. While not appearing to be an obvious issue or gap raised by the literature in Section 2.5, it is fundamental to essential services planning and a core strength of IRP. Forecasting requires having both a holistic and disaggregated view of the resource in question and the demand or 'service' required. Critically, a good forecast is developed through both top-down and bottom-up analysis, as described in Section 7.1.

Historically, forecasting in water was poor, with often wildly varying results depending on the timing of the forecasts and methods used. Commonly, a simple extrapolation of overall usage based on per capita demand multiplied by population and projected growth was used (Turner et al., 2010a, Fyfe et al., 2010; Heberger et al., 2016). This simplistic approach is still often used in waste management. In the case of water, in some jurisdictions this simplistic approach has given way to more sophisticated techniques such as end-use modelling and regression analysis (Fyfe et al., 2010; Heberger et al., 2016; Diringer et al., 2018).

Simplistic approaches to forecasting have tended to overestimate the demand for water, as illustrated in Figure 7.7. These over estimations not limited to the water sector but often also seen in energy, economics, demographics and politics. This overestimation in water has resulted in potential over investment in LTS supply-side infrastructure, in some cases not used for many years, and resulting in higher customer bills to pay for those assets (Heberger et al., 2016). Understanding resource use or generation through disaggregation (as discussed in Section 7.1) together with a better understanding of the factors that may influence those individual sectors over time fundamental to more accurate forecasting (Fyfe et al., 2010; Heberger et al., 2016; Diringer et al., 2018).

Figure 7.7 – Example of over estimation in water demand forecasting



(Source: Heberger et al., 2016)

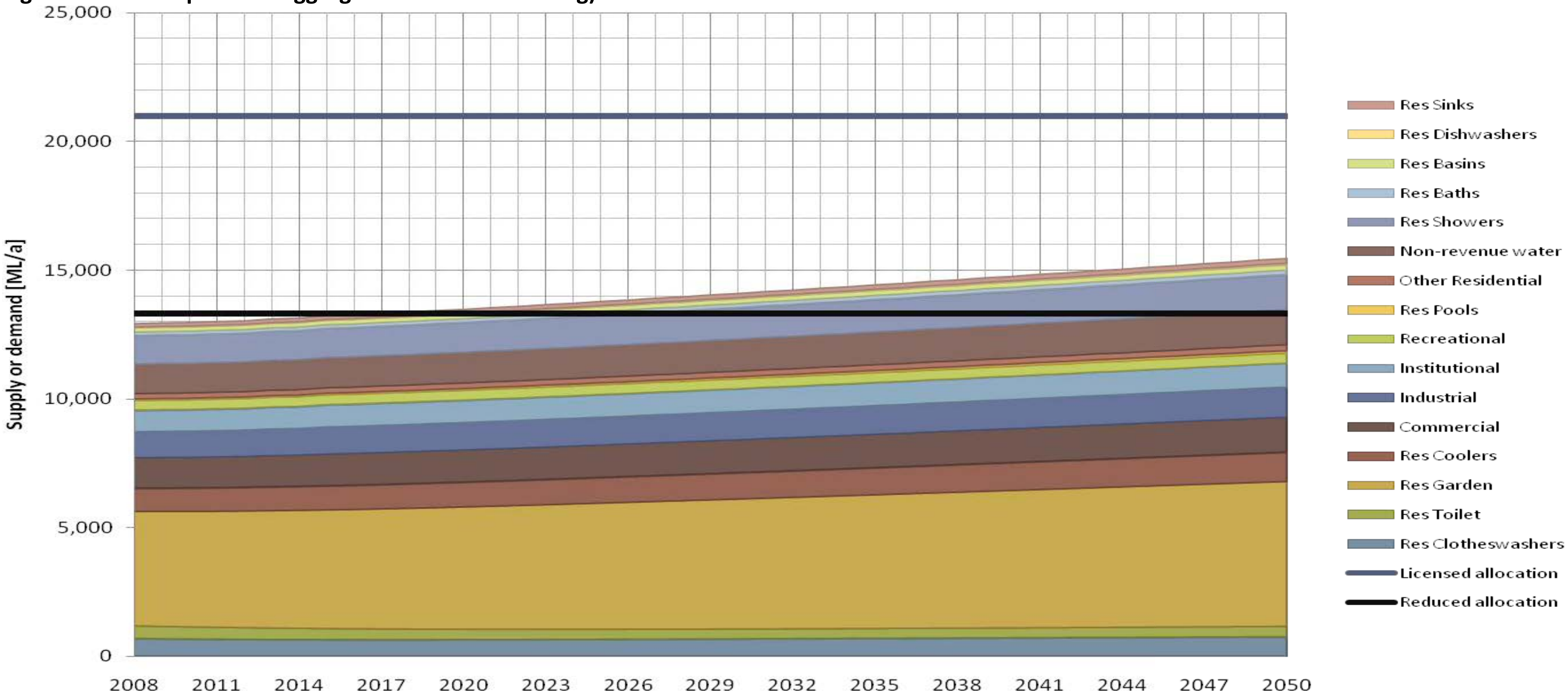
This emphasises some of the fundamental arguments used in IRP:

- the need for more detailed disaggregated demand analysis and factor-based forecasting
- the use of scenario planning that considers various drivers; although this particular aspect could be further strengthened in IRP by explicit consideration of trends versus shocks as highlighted be sustainability transitions (refer to Section 3.4.2)
- a focus on demand-side management and smaller scale, staged supply-side augmentation in line with growth in demand to avoid premature and/or unnecessary LTS investment.

Disaggregation of a resource at the sector, sub-sector, and, where possible, end use/micro component level enables more detailed context-specific forecasting. In water IRP, this is conducted through longitudinal assessments of the customer water meter demand by sector and sub-sector. It is combined with other longitudinal socio-technical studies such as end-use studies and the building of stock models to represent the turnover of various end uses/micro components (such as showers and washing machines) as technical and behavioural efficiencies change (Diringer et al., 2018; Turner et al., 2010a). Using historical longitudinal trends disaggregated at the component and sub-sector level, understanding of current resource demand at a detailed level, plus the factors driving demand (e.g. population growth, land use change, end use efficiency and urban density) enables a more detailed forecast, as illustrated in Figure 7.8. Again, this has been used in water IRP for decades, including in developing countries and emerging economies with poor or little data available, as indicated in Section 7.1.

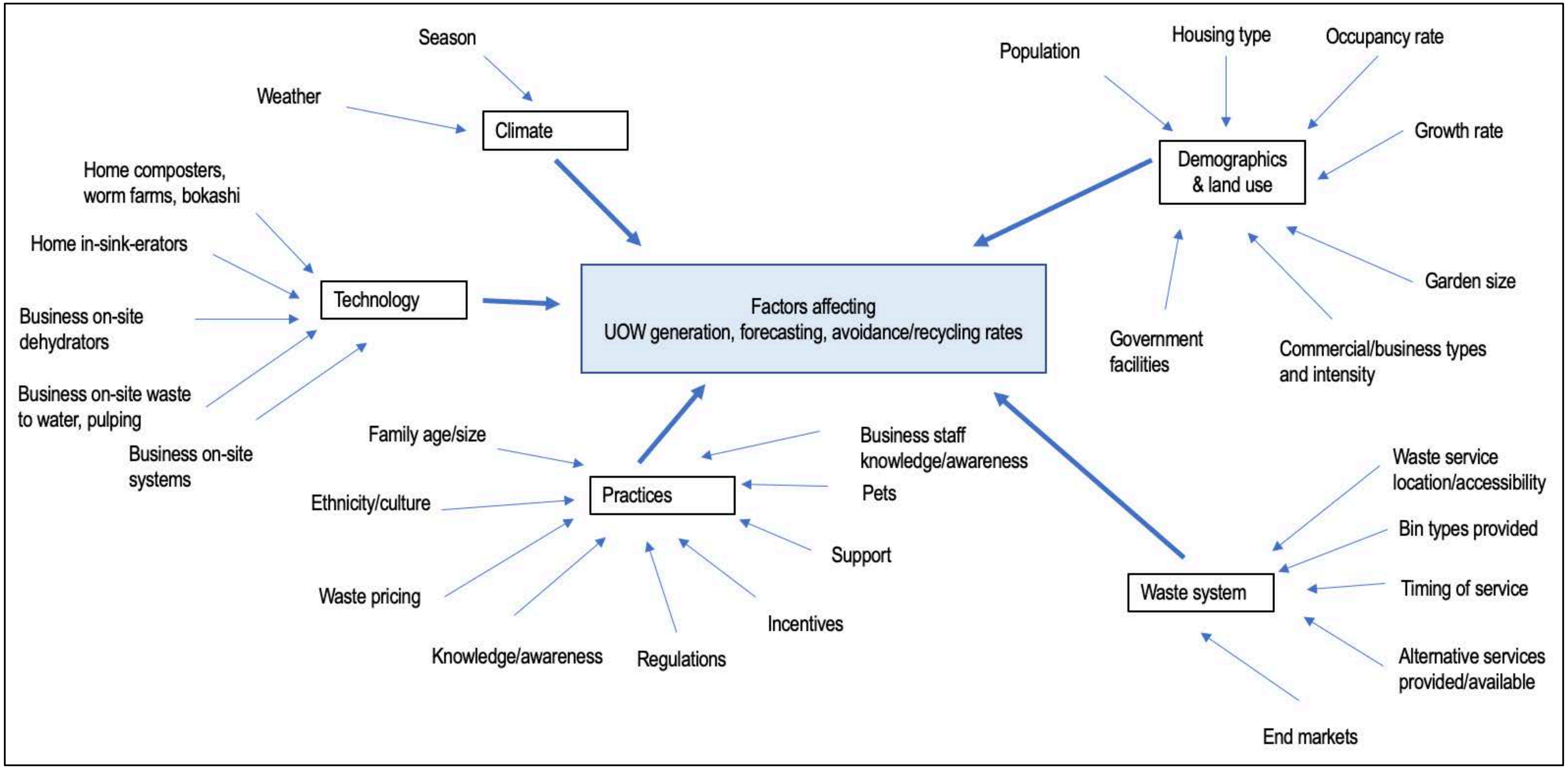
Unfortunately, as much of UOW is not measured and/or associated data is not publicly available, forecasting it is difficult and appears to often use simple per person or per household extrapolation methods. Despite the lack of data, more in-depth analysis is still worth attempting, as in the early days of water IRP when data was sparse. Such a disaggregated picture provides an indication of the current level of UOW generated in any given region in each sector and waste stream, how that might change going forward and what data gaps exist that need to be filled. Such a picture is essential when planning systems that need to deal with UOW situations with multiple rapidly changing circumstances, such as those in Sydney. That is, rapid urban development and densification such as the shift from SUDs with gardens to MUDs with little outdoor space, increases in the take-up of on-site avoidance and processing (e.g. home composters and dehydrators in businesses), and new emerging socio-technical innovation. Figure 7.9 illustrates the kinds of factors that need to be considered for UOW, which will vary significantly from jurisdiction to jurisdiction.

Figure 7.8 – Example of disaggregated water forecasting)



(Source: ISF, 2011)

Figure 7.9 - Factors that need to be considered when forecasting UOW)



(Adapted from White et al., 2003)

As in the water industry, knowledge on the details of some UOW sectors is more advanced than others. For example, as identified in Section 4.3.3 and Table 7.1, there are longitudinal audits in Sydney on residential bins and their content (APC, 2019a; Rawtec, 2020) for SUDs, MUDs and now also for the growing high-rise MUDs sector, that could aid bottom-up estimations. These can be compared to what could be used as top-down measurement through the WARR reports submitted to the NSW EPA by councils on an annual basis (see Table 7.1). Although, care is needed when using these data sources. For example, there is difficulty in uncovering statistical assumptions and limitations in audits due to a lack of consideration of seasonal variation or underlying previous/current demand-side management. Despite these limitations they provide useful preliminary datasets.

However, there is much less known about the non-residential sector in terms of representative audits or overall measurement. What limited data there is available is relatively dated (NSW DEC, 2003; NSW DECCW, 2010b; NSW EPA,2015a; 2015b), not available to the public or difficult to analyse (NSW EPA, 2016). As indicated in Table 7.1, figures on other UOW streams such as used cooking oil are not publicly available. Although such data can potentially be obtained from the limited number of used cooking oil waste management collectors or from private market segmentation industry reports, although at a significant cost[21]. This indicates that UOW in the residential sector might be more easily modelled and forecasted than the non-residential sector streams initially.

7.2.1 CASE STUDY ILLUSTRATION

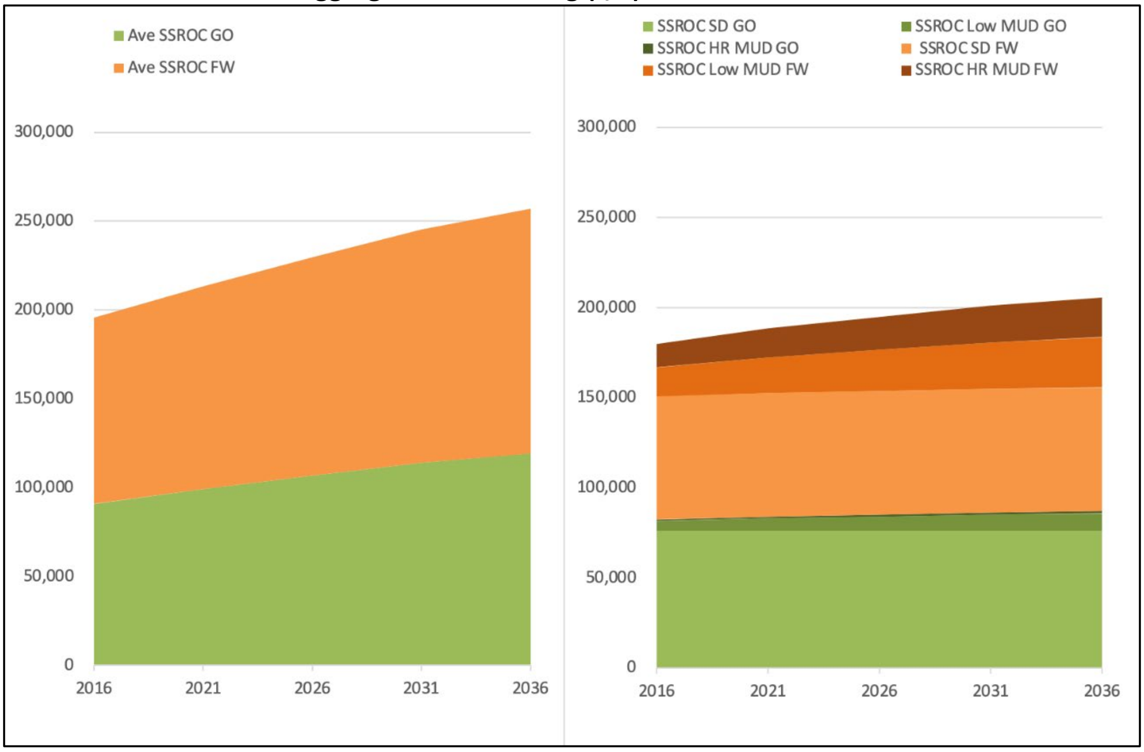
Forecasting was not conducted for the CP or PUP case studies, as they were assessed as ’snapshots in time’. Forecasting was attempted for the IWC case study for both the residential and non-residential sectors, although this was difficult as population figures and planning growth corridors were being discussed between the state and local governments at the time. This kind of uncertainty provides an example that lends itself to scenario planning, to help assess the implications of varying forecasts.

To illustrate the use of using various datasets and the importance of considering various factors that affect UOW generation and forecasting, Figure 7.10 provides a simplified illustration using the Sydney-based SSROC area. It focuses on the residential food waste and

[21] https://www.ibisworld.com/au/industry/edible-oils-manufacturing/5480/

garden organics that councils are used to managing and what data is available, although much of the data not public. SSROC represents over 40% of the population of the GSC and SMA areas, as identified in Section 4.3.3.

Figure 7.10 – Illustration of average kg/household/a food and garden organics forecasts versus more detailed disaggregated forecasting (t/a)



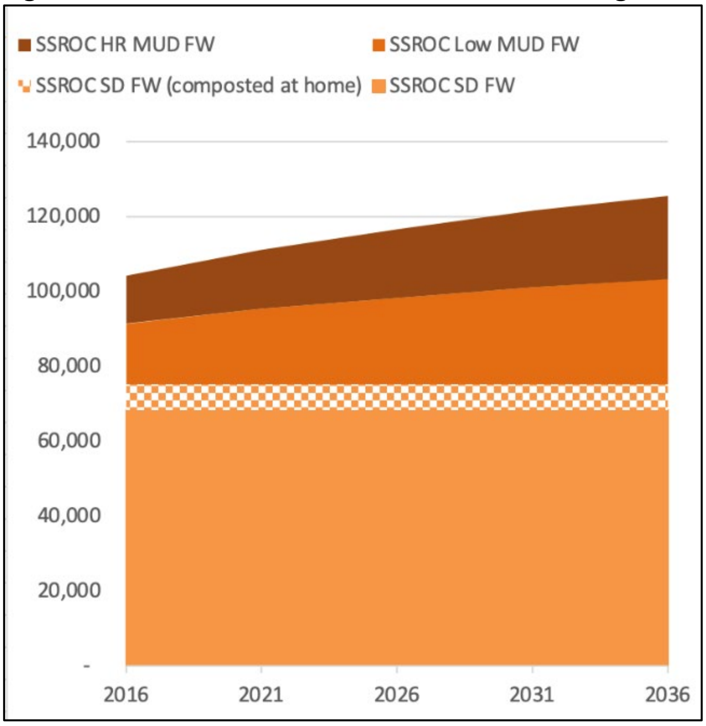
Based on available data, the illustration compares a forecast based on a standard overall kg/household/a projection, where current average food waste and garden organics generation are extrapolated based on overall household forecasts, with that of a more disaggregated view. The disaggregated view considers how the proportion of SDs and MUDs and the average food waste and garden organics within those property types varies and might change as part of the forecast. For example, urban densification and the stagnation of SDs growth, and actual decline in overall SDs figures in the last decade in much of the SSROC area (.id, n.d.-b) compared to the significant anticipated growth in high- rise MUDs according to NSW Government policy (GSC 2018a). For illustrative purposes the growth assumed here is split 50/50 (low- to high- rise MUDs) for all new households and with stagnation of SDs. This is the trend seen in historical records of much of the area (Id, n.d.-b). This household forecast was combined with typical tri-annual kg/household/a audits for SDs and MUDs (APC, 2019a). These kinds of datasets have been collected by some councils in the area since the early 1990s and thus provide the potential for time-series analysis, as attempted by Rawtec (2020). Although, there are limitations in this analysis, such as one-off measured audits not taking into consideration seasonality within a given year, variation in kerb presentation rates and not observing interventions over time that could affect waste generation, as discussed in Section 4.3.3.

This illustration takes into consideration the new audit data on high-rise buildings conducted by five of the nine SSROC members. As discussed in Section 4.3, the original tri-annual audits exclude MUD properties over three stories, as such buildings have the potential to skew the relatively small datasets collected. This exclusion was not really seen as an issue historically but is now for several SSROC members, as much of their existing and future growth are high-rise MUDs over three stories (as illustrated in Section 4.2 Figure 4.6). For example, high-rise MUDs dominate within the City of Sydney Council region at approximately 75%, compared to only 24% in the Sutherland Shire Council (id. n.d.-b). This illustrates the importance of further disaggregation and granular assessment of individual areas and trends.

While the forecasts, by necessity, use different audit data and start at slightly different tonnages, they illustrate the usefulness of disaggregation, and in this case, the potential dampening in UOW growth for households under BAU when the detail of a region is considered. In addition, they also show how the growth in MUDs, especially high-rise MUDs, may affect both food and garden organics waste anticipated as well as potential treatment solutions. For example, despite such anticipated growth in MUDs, existing SDs remain the dominant source of food and garden organic waste and a key focal area to achieve avoidance targets. While the growing high-rise MUDs sector will probably need a different approach focusing on food waste only collection and treatment, such as AD or forms of on-site treatment.

Based on limited available data, Figure 7.11 includes assumptions on the uptake of simple home systems such as composters and worm farms in SDs and how such 'hidden' organics can also affect forecasts. According to recent national figures, around 18% of households compost food waste at home (FIAL, 2021). According to extracted data for the IWC, 20% of households purchased some form of composting or worm farm equipment from Compost Revolution between 2015 to 2020 (i.e. only one retail outlet of several available but advocated by the council as part of a food waste program for several years). Hence, assuming 20% of SUDs treat 50% of their food waste at home, as estimated by recent analysis of audits within the IWC (APC, 2019b), this represents a sizeable quantum of potentially 'hidden' waste not even accounted for in forecasts. A potentially greater hidden quantum can be expected for garden organics composted at home.

Figure 7.11 - Detailed food waste forecast including 'hidden' home composting in t/a



The difference in food and garden organics between the two forecasts (shown in Figure 7.10 by 2036), illustrates the equivalent of 50 kt/a of planned LTS in Sydney. That is, the equivalent of EarthPower, the only commercially available AD plant in Sydney or one of the planned AD plants within the 20-year waste strategy (NSW DPIE, 2021b), and considerable investment that might not actually be needed.

In terms of the non-residential sector as identified in Section 4.0, a concerted effort is required to fill knowledge gaps to help facilitate even basic modelling and forecasting. The IWC case study helps to fill this gap, to some extent, for a snapshot in time using analysis of disparate data sources. The CP case study is useful for providing rare, measured data available in the public domain. However, much more is needed to facilitate even basic forecasting similar to that above, conducted for the residential sector.

7.2.2 BROADER IMPLICATIONS

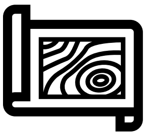
With so many changes in UOW occurring from a shift from separate dwellings to MUDs of varying density, increases in home composting and growth of on-site treatment of food waste at non-residential properties, UOW generation will continue to change per property type across Sydney and indeed many other jurisdictions in Australia. Important factors need to be taken into account in UOW planning if similar mistakes to the water industry forecasting and associated LTS capacity augmentation are to be avoided, and indeed if effective evaluation of UOW policies and programs are to be measured going forward.

As with UOW generation, there is currently no co-ordination of data relevant to forecasting organic waste volumes in Sydney. That is, no registration of on-site treatment equipment in Sydney or NSW, with Sydney Water and NSW EPA only requiring licences/agreements for some technologies and little co-ordinated measurement or analysis. For example, Sydney Water may require a licence for an on-site technology that discharges to the sewer, but self-contained food macerators regularly pumped out do not appear on either Sydney Water, nor NSW EPA registers. Hence, there are significant hidden organics already being managed and an opportunity for cross-sectoral co-ordination of registration of UOW management technologies at various scales (on-site to centrally managed) and measurement and reporting of materials managed. This would facilitate clarity on the hard and soft UOW system being managed within each LGA, in Sydney and across NSW. Such clarity invaluable in garnering a greater estimation of current and projected resource generation, quantities already being managed by various socio-technical systems, and the quantities that remain to be managed. This picture of historical, current and projected UOW essential for managing the system going forward.

Core organics infrastructure requirements for Sydney and regional NSW have been released for the next 20 years (NSW DPIE, 2021b). The assumptions around forecasting are unfortunately not available and thus unclear in terms of the level of disaggregation or whether any of the factors above were incorporated into such important decision-making analysis. Nor were the full suite of UOW streams considered, despite 'organics' being the focus of the new NSW targets.

While the direct use of IRP forecasting is difficult in the UOW sector due to the significant paucity in data, it is a useful approach to help draw disparate sets of data together to form both a holistic and disaggregated view as well as an assessment of the factors affecting UOW generation both historically and going forward. As with the water sector, the IRP disaggregated forecasting approach is a way to account for trends at a component and sub-sector level and to be able to identify specific data gaps that need to be filled over time and thus a key area of research that needs to be taken forward for UOW.

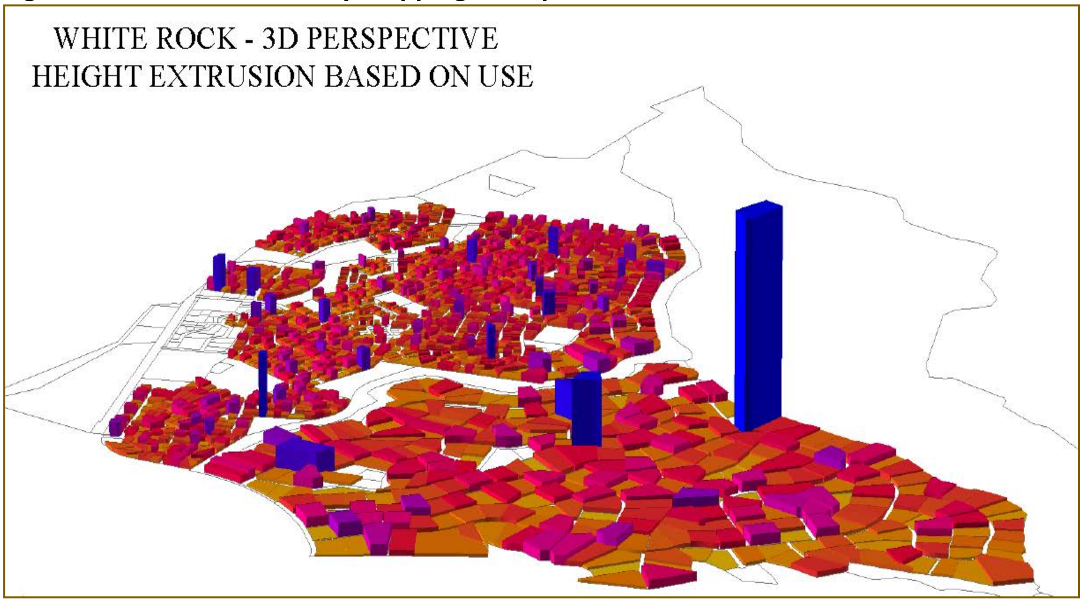
7.3 MAPPING & VISUALISING THE RESOURCE SYSTEMS



As identified by Asefi et al. (2019) and discussed in Section 2.5, the use of GIS visualisation could significantly assist in improving stakeholders understanding of and engagement with complex waste management systems and help improve decision-making. Such methods provide another dimension to exploring contextual detail.

The use of such geospatial mapping and visualisation in the water IRP process is not traditionally practiced. The exception being in terms of identification of the overall ‘hard system’ or network within the boundary of analysis and identification of various relevant catchment areas or similar. Historically, geospatial mapping of water use occurs in only limited cases. For example, Figure 7.12 from the US, as a tool to assist in granular identification of high-water users and consideration of associated potential option design and implementation to target reducing high water usage. This form of mapping is usually restricted to internal service provider use due to privacy issues. With the availability of more advanced geolocated smart water meters and improved interfaces, in recent years, intensity mapping has emerged as a useful geospatial mapping approach in Australia. For example, customer usage and system water leaks are an area that could be further explored for water IRP application more broadly (Turner, 2015). That is, to inform Step 2 disaggregation and forecasting analysis as well as Step 3 targeted option design. Although again, this is likely restricted to internal service provider use due to privacy restrictions.

Figure 7.12 – Water intensity mapping example from California



(Source: Dickens, 2013. Reproduced with permission of author)

Looking at UOW management, while there are a few international examples of establishing high resolution estimates of biomass resource availability to help geospatial analysis and management in a given area (Voivontas et al., 2001; Shi et al., 2008; Comber et al., 2015; Lozano-Garcia et al., 2020), this is generally lacking, especially in the Australian context. This gap is in terms of granularity, organics streams and/or the urban context, with only limited examples currently publicly available (Johnson et al., 2015; Metson et al., 2018; Wesley, 2020; ARENA, n.d.; Madden et al., 2020).

7.3.1 CASE STUDY EXAMPLES

All three case studies applied novel geospatial mapping for various purposes and at different scales, helping to fill this gap in the Sydney context and demonstrating its potential for broader UOW application, and indeed incorporation in IRP practice.

Three GIS visualisation methods demonstrated in the case studies were:

- intensity hotspot mapping
- asset overlay
- route mapping.

These are discussed below.

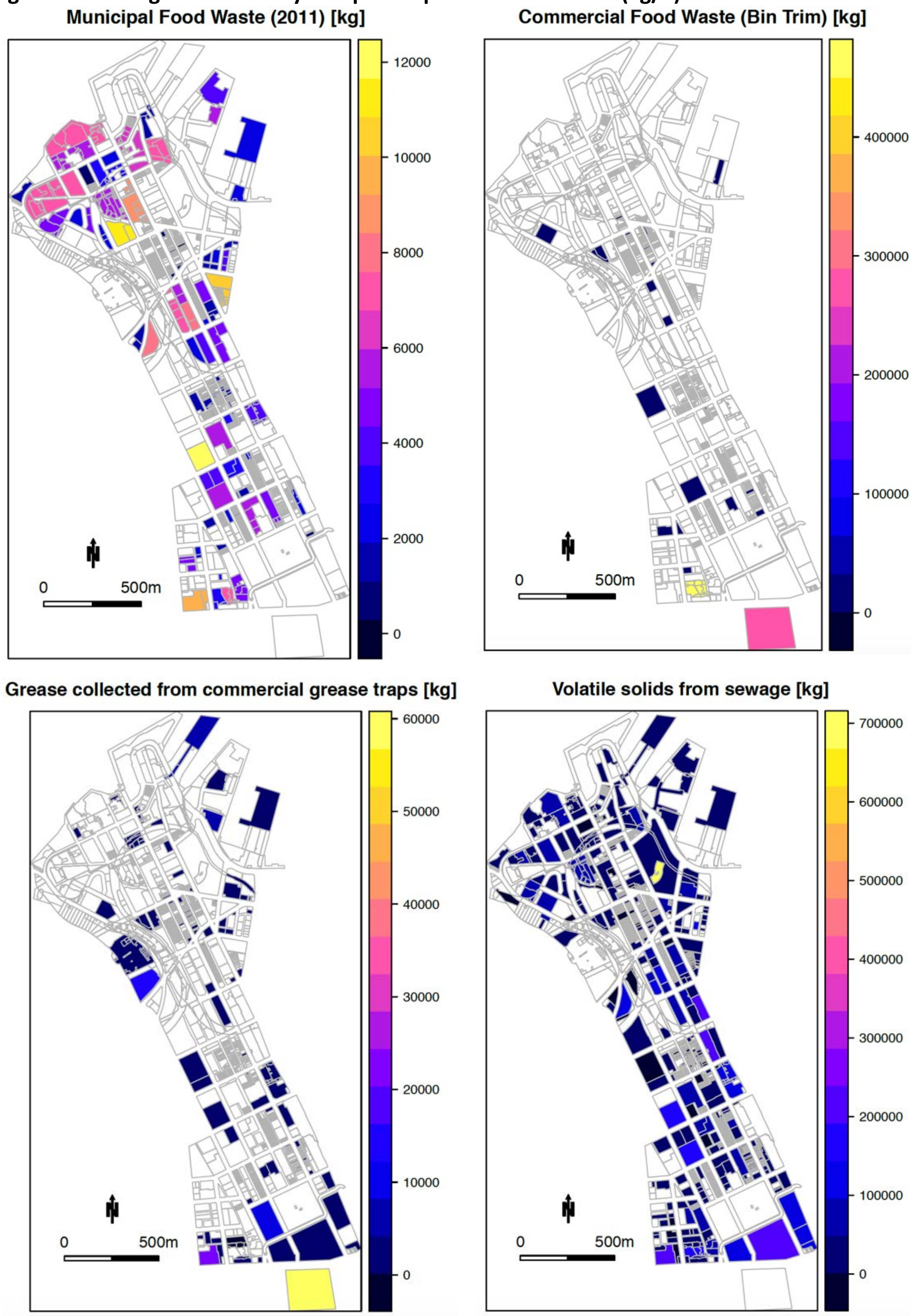
7.3.1.1 INTENSITY HOTSPOT MAPPING

The PUP and IWC case studies helped illustrate, for the first time, the use of geospatial hotspot mapping in UOW management at the sub-LGA and LGA scales. This mapping identified the 'intensity' of various streams of organics (i.e. garden organics, residential food waste, non-residential food waste, used cooking oil, fats, oils and greases, wastewater biosolids, trade waste) where data was available in terms of volumes or mass. As identified in Section 7.1, the input data for analysis was often from disparate sources not combined into a holistic picture, and with varying availability, privacy and quality issues that needed to be overcome. Such intensity hotspot maps are able to be viewed both individually (i.e. a single GIS layer on a particular stream, see Figure 7.13), and collectively (i.e. combined layers, see Figure 8.2 in Section 8.1). They provide a powerful tool to assess where hotspots of organics might occur in a particular location in terms of volume or mass.

The intensity mapping also enabled the associated 'potential' of those organics to be geospatially mapped for the first time. For example, fats, oils and greases have higher potential for AD co-digestion treatment and bioenergy generation compared with cellulous/lignin rich garden organics better suited to composting, and food waste has higher nutrient value compared to fats, oils and greases. This examination of both the individual volume or mass and energy or nutrient potential is particularly useful in aiding options design for a specific context and tailoring options to achieve specific objectives. That is, filtering available data to examine specific types of materials in the residential and non-residential sectors and sub-sectors and specific substrates present that may generate a specific type of UOW that can be used for higher order circular economy benefits. Or materials that can be used to design specific programs to achieve energy generation targets (i.e. use of AD). Or indeed, materials that can be used for both.

The PUP case study was the first time disparate datasets were drawn together in the Sydney context (i.e. data from Sydney Water, NSW EPA and the ABS as well as data sourced from individual sites). In the IWC case study, with council involvement, the collation and analysis of additional datasets held by IWC were possible (i.e. Australian Tax Office business data and council assets). Refer to Table 7.1. In both cases, there is significant room for improvement in data quality, coverage and associated analysis that could be enhanced by crosschecking and pooling cross-sectoral datasets as discussed in Section 7.1. Despite this, they demonstrate significant practical potential in the analysis methods used.

Figure 7.13 – Organics intensity hotspot maps for the PUP area (kg/a)

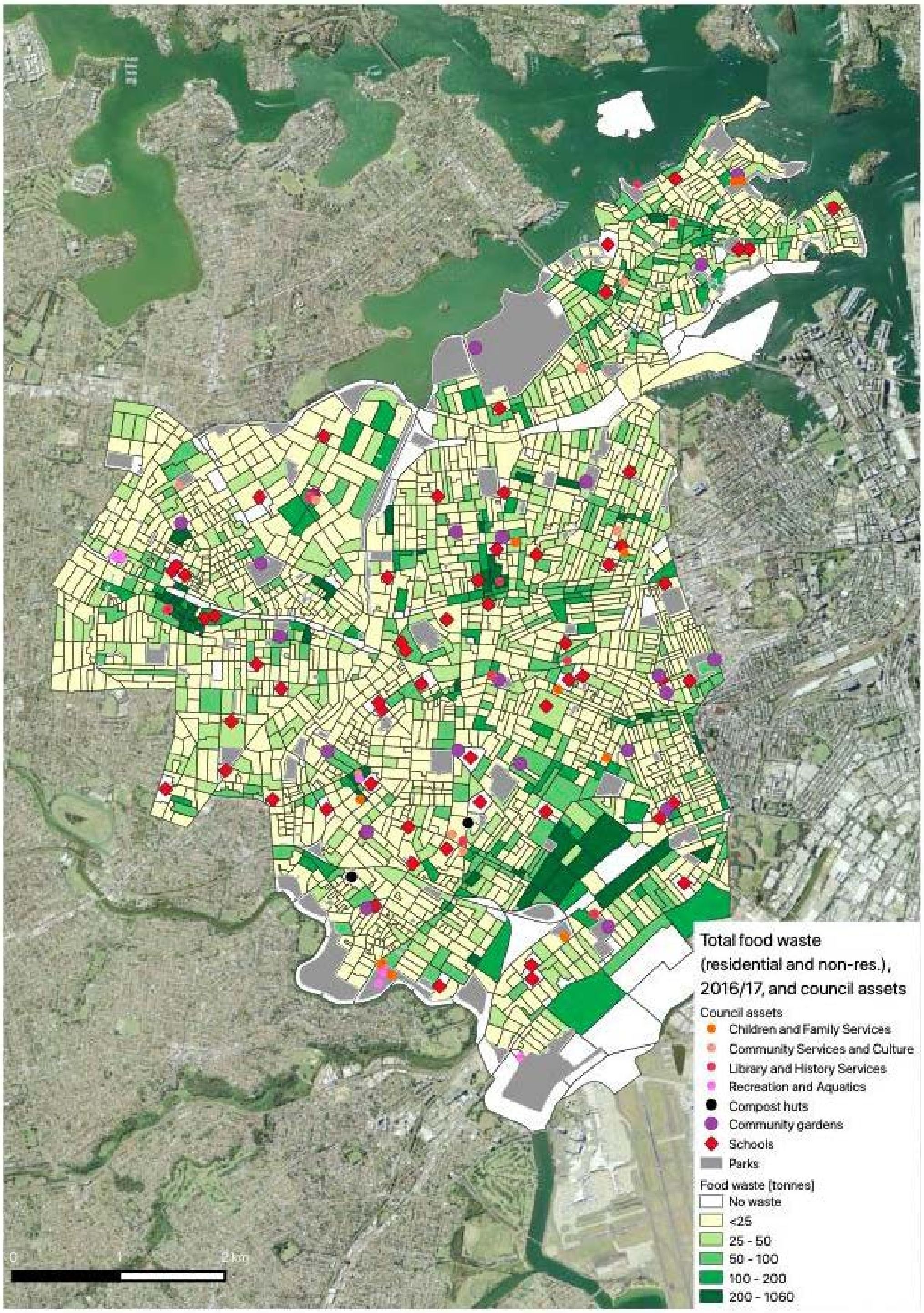


(Source: Turner et al, 2017)

7.3.1.2 ASSET OVERLAY

The IWC case study went further than the PUP case study due to access to additional datasets and consideration of a larger LGA scale. This included demonstration of additional GIS overlaying methods. As shown in Figure 7.14, IWC assets such as child care facilities and community gardens, along with other government assets such as schools were combined with food waste intensity maps for the residential and non-residential sectors. This provided a visualisation of both the core IWC/government assets that could potentially generate significant quantities of organics but also be used to help collect nearby residential and non-residential food waste, (e.g. council depots) and provide potential local scale UOW collection and treatment solutions. Such maps were subsequently used as a 'device' to engage IWC staff in detailed options development and discussions on detailed criteria for choosing potential options. Such visual devices are commonly used in both systems thinking and transition management as an essential tool for stakeholder engagement.

Figure 7.14 – Example of residential and non-residential food waste intensity hotspots overlaid by council asset locations



(Source: Jazbec et al., 2020. Reproduced with permission of authors and client)

7.3.1.3 ROUTE MAPPING

Another form of mapping conducted for the CP case study was an assessment of the current routes used for treatment and disposal of individual UOW streams and organic-rich streams from a single building/precinct, as shown in Figure 7.15 (a). This mapping shows the current fragmented approach to UOW management for just one building/precinct scale development and the significant distances incurred for such treatment and subsequent recycling or disposal. The mapping was similarly conducted for the IWC case study, for the entire IWC LGA, see Figure 7.15 (b). In both the CP and IWC case studies, the mapping shows that a proportion of the waste passes to Goulburn for treatment, some 200 km south of Sydney.

Such mapping provides baseline information for route optimisation and assessment to reduce truck movements, road congestion and transport GHGs. Further research is currently being conducted for the residential sector in Sydney (Madden et al., 2022). The use of such mapping can also be used to engage stakeholders to consider more tailored localised avoidance and treatment options and the associated benefits. This is further discussed in Section 8.1.

7.3.2 BROADER IMPLICATIONS

The GIS visualisation of UOW intensity hotspots, assets and route mapping demonstrated by the three case studies illustrate a deeper level of contextual detail at various scales and how this can assist in helping stakeholders understand complex UOW management systems and improve engagement. Aesifi et al. (2020) recently advocated for this more generally in waste management. GIS visualisation can also assist in illustrating the impacts of the current situation and potential benefits of different options, including more localised treatment.

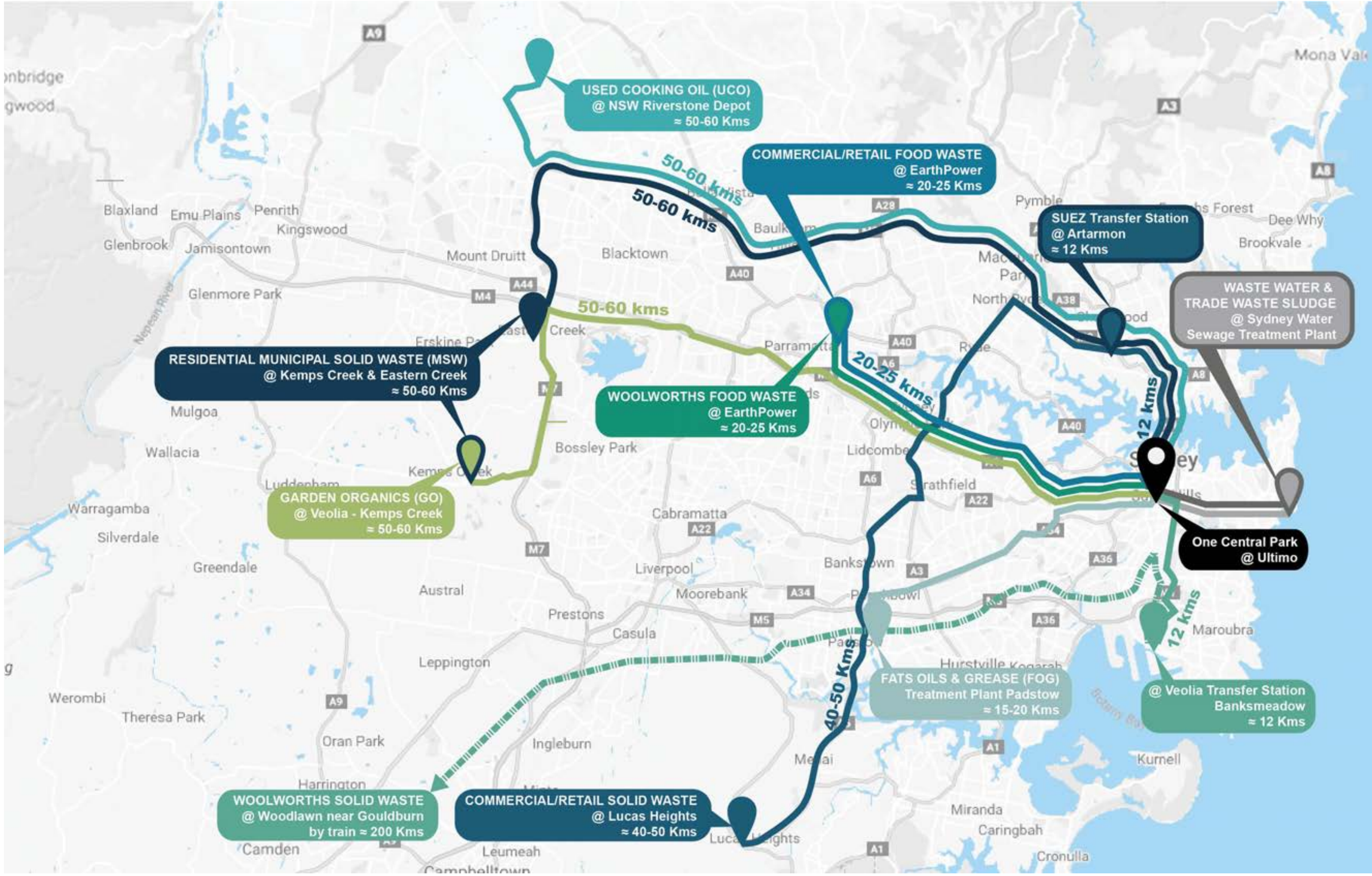
While such visualisation is not currently used extensively in UOW management nor water IRP, it has significant potential that warrants tailored research and application. Indeed the potential benefits are already being taken up through research projects such as '*Mapping Organic Waste in Sydney: Advancing Anaerobic Co-Digestion for Energy Generation and GHG Reduction*' (Jazbec et al., 2023), which I am leading as a Chief Investigator for RACE for 2030[22]. This current project builds on the case study projects and demonstrates the ability of GIS visualisation to provide cross-sectoral interest in UOW (waste, wastewater, energy). The research beginning to explore methods to pool cross-sectoral data and generate maps to aid in

[22] RACE for 2030 is a 10-year industry led cooperative research centre established in 2020 with AUD 68.5 million of Australian Government funding with the overall aim of accelerating the transition to reliable, affordable, clean energy for 2030.

stakeholder engagement at larger scales within Sydney, with the potential to be applied across the city and in other jurisdictions.

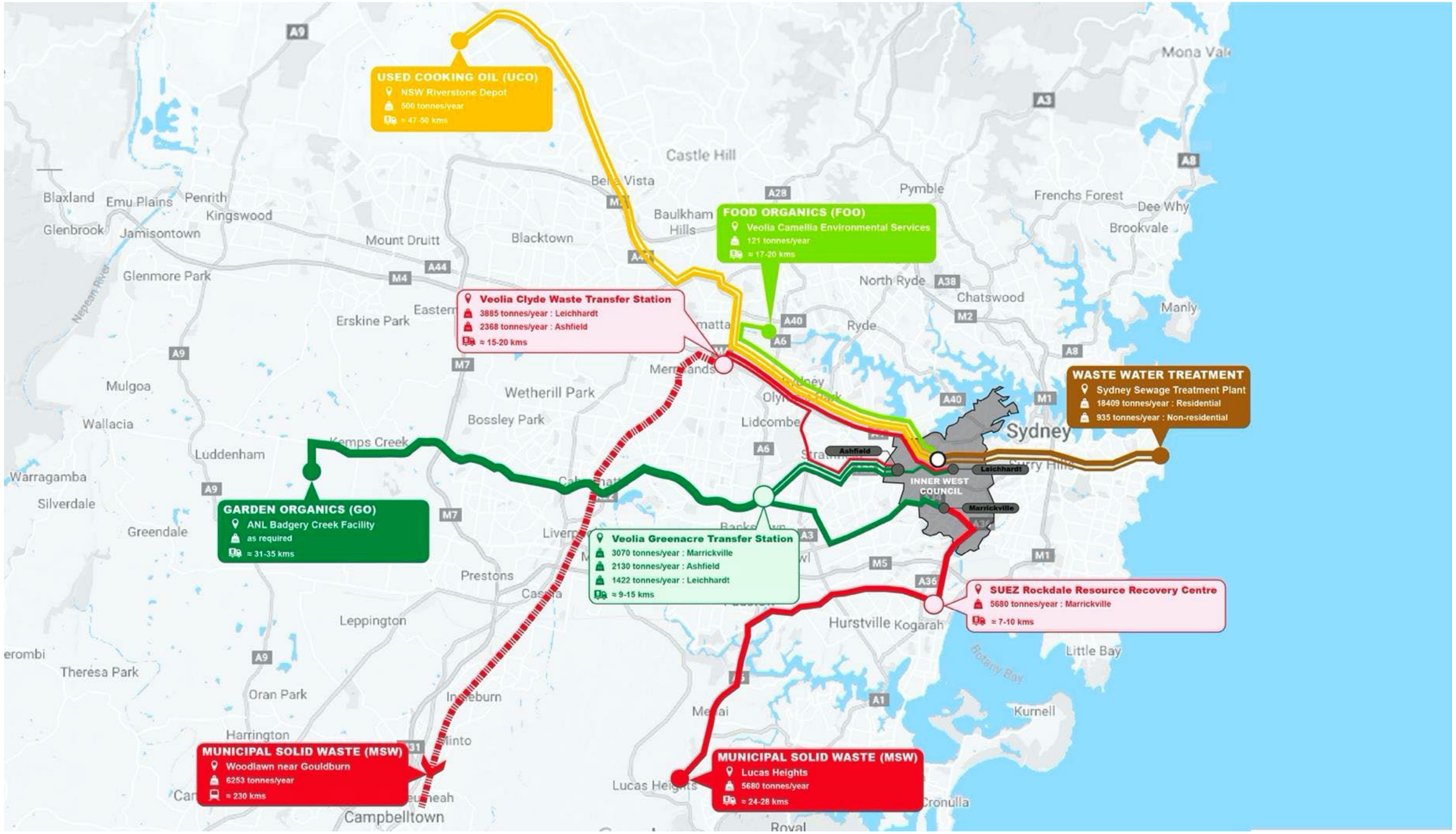
This Section has explored how methods such as resource disaggregation, forecasting, and GIS mapping and visualisation (IRP Step 2) can assist in unveiling the detailed context of UOW generation and management. The next section focuses on the identification, development, costing and assessment of options (IRP Step 3) that build on IRP Step 2 analysis and aid decision-making.

Figure 7.15 – Organic waste stream routes and treatment/disposal destinations
(a) CP case study



(Source: Turner et al. 2017)

(b) IWC case study



(Source: Jazbec et al. 2020. Reproduced with permission of authors and client)

8 DEVELOPING & ASSESSING A BROAD NETWORK OF OPTIONS (IRP STEP 3)

This Section focuses on the gaps and opportunities identified in Section 2.5 relating to developing and assessing options, and specifically how IRP (Step 3) concepts and methods might help fill some of those gaps and opportunities for UOW. This includes how to better consider and/or incorporate:

- a broader network of complementary options relevant to a particular context, including preservation of resources (i.e. prioritise avoidance)
- drivers, pressures, cross-sectoral impacts and trade-offs
- the risk of LTS lock-in and adaptive management and innovation lock-out
- integration of GIS visualisation methods to help engage stakeholders.

As identified in Section 3.2, IRP is strong both conceptually and methodologically when considering options. However, UOW raises additional challenges, which highlight the benefits of potentially augmenting IRP with systems thinking and sustainability transitions. Hence, this Section focuses on filling the options related gaps using IRP, systems thinking and sustainability transitions and testing the associated concepts and methods in the Sydney-based case studies. These concepts and methods are discussed in the following sections in terms of:

- identifying and developing options
- costing and assessing options.

8.1 IDENTIFYING & DEVELOPING OPTIONS

As identified in Section 2.5 and reiterated in Section 7.1, there is a need to move away from silver bullet solutions and towards 'networks of complementary options' that respond to the 'drivers, pressures and context' of an area being examined. These insights were identified in an international review by Spang et al. (2019), and extended by Mourad (2016) and Redlingshöfer et al. (2020), by specifically highlighting the need to address 'avoidance' and consider different 'scales' of socio-technical solutions. 'Avoidance' is highlighted because, despite being a priority of the waste hierarchy, it is under-represented. 'Scale' raises the question of whether LTS might actually increase waste through, for example, lengthening commodity chains and seeing organics more as a resource to be harnessed rather than to be avoided at the source. These international reviews and insights are related to food waste but are equally relevant to broader UOW streams. This is due to food and other UOW streams being such a major component of waste, causing detrimental impacts if not managed effectively, and having diverse sources and characteristics that cannot be effectively managed by a single solution. These insights are particularly pertinent in Australia, where food waste and other broader UOW streams are being identified in waste management strategies at various levels of government as essential to help achieve overall waste reduction and policy objectives (CoA, 2017; NSW DPIE, 2021a).

Since the last century, in both water and energy, IRP has helped unveil the significant opportunities available from demand-side solutions. For water, this is in the form of more efficient technologies (e.g. efficient showerheads) and associated behaviours (e.g. shorter showers) as well as the use of alternative sources (e.g. rainwater tanks and recycling). As identified in Section 3.2, IRPs unique focus is on the 'service' not the commodity (or 'function' in systems thinking lexicon) and demand-side solutions specifically aiming to prioritise efficiency or 'avoidance' and respond to 'drivers, objectives and service needs' in a particular 'context'. Thus, the IRP approach responds well to many of the key waste management gaps and opportunities identified in Section 2.5.

In addition, IRP, while not explicitly using sustainability transitions theory, has helped the ongoing transformation of the water and energy essential services sectors. This has been achieved by reducing reliance on LTS silver bullet solutions and helping planners and decision-makers actively focus on a 'mix of options' of varying 'scales'. Such transformation typically takes the form of the gradual embedding of smaller-scale socio-technical systems within the existing incumbent hard system network (i.e. a 'hybrid' system), where efficiency is prioritised. The prioritisation of efficiency has subsequently led to the implementation of significant numbers of demand-side solutions in Australia, spurred on by the Millennium Drought 'window of opportunity' (refer to Box 6). This has led to diverse impacts, including (Turner et al., 2016):

- a move away from the vulnerability of relying on traditional LTS and associated 'lock-in' (e.g. unreliable rainfed dams)
- the opportunity to embrace socio-technical 'innovation'
- the ability to capture 'cross-sectoral benefits' (e.g. water and hot water energy savings from efficient showerheads)

- a move towards 'adaptive management' by filling the supply-demand gap in smaller increments to avoid over investment in costly LTS and supply-side assets potentially not used for years (e.g. the AUD 2 billion Sydney Desalination Plant, refer to Box 5).

Hence, again, many concepts used in water IRP respond well to the gaps and opportunities identified in Section 2.5 and the UOW management transformative change advocated.

When considering waste, avoidance has been a priority in Australia, as identified by the waste hierarchy for well over a decade (Giurco et al., 2015). However, such avoidance has typically focused more on 'avoidance from landfill' (i.e. lower-order recycling), not 'avoidance from generation' (i.e. avoidance at the source). This is a point of ambiguity for those responding to the targets, as discussed in Section 1.2. For organics in the waste sector, the material has mainly been managed through household garden organics separation, collection, and treatment at central LTS composting facilities. It has also been managed through post separation of municipal waste in red bins through LTS such as AWT/MBT facilities, where available. Although, this method is now limited in NSW due to concerns over soil contamination from the end product (refer to Box 1). Where pre and post separation is not available, the organics typically end up in landfill.

UOW avoidance (e.g. menu planning, fridge management) in both the residential and non-residential sectors is advocated by government programs. Also, traditional and innovative ways of treating UOW at various scales (e.g. home composters, café dehydrators) are encouraged, incentivised and implemented. In addition, significant funding has been provided over the last decade to help drive various forms of organics management other than disposal (refer to Sections 1.2.4 and 4.3.5). However, despite such investment and growing interest in avoidance and on-site solutions, they are still somewhat ad hoc and limited in scale, and little is known about their implemented numbers or efficacy. Meanwhile, the continued drive by federal and state governments is mandating councils to implement LTS FOGO services despite concerns, with over 40 councils in NSW already providing the service, although virtually all are in regional areas not in Sydney, as discussed in Section 1.2.4.

Such focus on LTS is commonly observed in sustainability transitions, where the existing incumbent dominates (see Section 3.4.2). In Sydney, the incumbent is the private waste management oligopoly, which is understandably reluctant to invest in new facilities without 'guaranteed' feedstock and profitability. This is at odds with the 'avoidance' of generating food or other UOW in the first place, and contributes to the continued focus on lower-order LTS recycling, which is also observed internationally (Mourad, 2016; Redlingshöfer et al., 2020). With the inclusion of AD (and potential for bioenergy) in the NSW waste strategy (NSW DPIE, 2021a; 2021b), it is likely there will be more 'demand' for UOW to 'feed' new assets. This is likely to increase the 'tension' between avoidance, local treatment and LTS solutions. With such tensions created by policy, there is a need to open up and transparently consider the full spectrum of options available to multiple stakeholders generating (and potentially managing) UOW across scales to avoid potential LTS lock-in, adaptive management and innovation lock-out, and negative impacts of option interactions. IRPs approach is specifically designed to do this. Hence again responding well to the identified gaps and opportunities.

Another strength of IRP, less obvious in other planning and decision-making approaches, and responsive to the identified gaps and opportunities for UOW, is the direct linking of options to the objectives, services and context being examined (i.e. IRP Step 1 and 2). Such purposeful linking is possible due to disaggregating the resource (demand for water or generation for UOW) in as much depth as is feasible with the data available. This is in conjunction with garnering insights on what sectors and sub-sectors use or generate those resources, as discussed in Section 7.1. Such value-context-alternatives focused thinking (extending Corner et al. [2001] value-alternatives iteration concept) is discussed further in Section 8.2.

Importantly, where IRP has been applied, dozens of potential demand-side solutions are typically identified and developed using systematic divergent thinking to enable comparison with supply-side options. Consideration of diverse UOW options and the use of a mix or portfolio of options together to reduce or offset the need for LTS is not considered in the same way as that found in the water and energy sectors and provides a significant opportunity.

Innovative options are often assessed as part of IRP options development. They are then piloted and implemented as part of IRP Step 4. They are not, however, necessarily actively considered. Active consideration of innovative solutions is particularly relevant now during this period of rapid growth in technology and associated socio-technical engagement brought about by the fourth industrial revolution (N Davis, 2016). Hence, sustainability transitions concepts, especially the interplay between transitions management and strategic niche management (Loorbach & Raak, 2006; Mourik & Raven, 2006; Raven et al., 2006), is also important and would be a beneficial addition to IRP more generally.

While IRP has so many strengths in terms of identification and development of options, again, due to the complexity of UOW, an additional general methodological improvement could be attained from mapping and visualisation, as advocated by Asefi et al (2020). This not only in terms of helping stakeholders in understanding and engaging with complex systems but also providing the potential to target options to specific locations, thereby further improving decision-making. As indicated in Section 7.3, geospatial mapping of water demand is not typically undertaken in water IRP. With water IRP, options are generally considered across an entire region, city or town (Turner et al., 2007; Turner et al., 2016) and programs are offered across a jurisdiction (e.g. showerhead exchange program), often for equity reasons, unless it is a targeted program (e.g. public housing). There are instances of more 'local IRP' used to help consider the benefits of demand-side options at a more local scale, such as a constrained water treatment plant or decentralised wastewater reuse opportunities (CoS, 2012; ISF, 2010) but this has had little application in the Australian context despite its potential. The opportunities of targeting options through mapping and visualisation are explored in the Sydney-based UOW case studies.

8.1.1 CASE STUDY EXAMPLES

Two methods were applied in the UOW case studies to help identify and develop options:

- developing an options inventory
- mapping and workshopping options.

Both methods push the boundaries of organics waste management in Sydney and Australia.

8.1.1.1 DEVELOPING AN OPTIONS INVENTORY

All three case studies involved identifying UOW options. The CP case study, however, was limited to on-site AD investigations as part of a targeted innovation grant supported by the City of Sydney council. Vacuum systems, an equally novel technology, were also considered as part of the study to explore the potential for food waste collection of these options. Both technologies were explored due to their novelty in both the Australian and global context at the building/precinct scale. In contrast, the PUP and IWC case studies were designed to use divergent thinking, based on IRP and systems thinking concepts and to help generate a broad spectrum of options for further development. This again novel, but this time in terms of the breadth of options considered. The options were first documented as 'vignettes' in the PUP case study and eventually as an 'options inventory' in the IWC case study.

The 2017 PUP case study aimed to expand the options considered for the sub-LGA by collating local and international examples of innovative UOW management. This was when few innovative solutions were actually being trialled or implemented in Australia due to various reasons, such as the following outlined by Turner et al. (2017):

- limited practitioner exposure to innovative practices being implemented overseas
- barriers to trialling or implementing new innovative approaches due to a lack of demonstrated experience in Australia
- ambiguous and expensive regulatory and testing requirements (i.e. output materials generated) of new technologies.

Such barriers are typical where innovative socio-technical systems are trying to break into an incumbent regime, as highlighted by sustainability transitions (refer to Section 3.4.2). Since the PUP study, despite these barriers, various new socio-technical solutions have begun to break into the market at various scales.

In the PUP case study, over 35 examples and additional sub-examples were summarised in short vignettes from an international grey literature and practice review (refer to Appendix A). To assist in divergent thinking, and to generate an array of UOW options to use for subsequent development purposes, considerations included:

- the various UOW streams (e.g. food waste, garden organics, used cooking oils, fats, oils and grease, wastewater, trade waste)
- the opportunities for various streams and combinations of streams (e.g. energy potential, nutrient recovery potential, valuable chemical extraction)
- the breadth of sectors (e.g. residential, commercial, institutional) and sub-sectors (e.g. SUDs, MUDs, cafes, restaurants, schools and hospitals)
- the scales of application (e.g. SUDs, MUDs, precincts, councils/LGAs, city)
- existing and new properties
- the food and other UOW value chain and system components (e.g. from generation to collection, transport, treatment, reuse)
- technologies (e.g. composters, dehydrators, aerobic treatment, AD)
- social and behavioural practices (e.g. menu planning, separation, community gardens)
- policy instruments (e.g. education, incentives, regulation)
- avoidance of generation through to reuse
- innovation (current and emerging)
- national and international examples.

While the divergent facets considered were not exhaustive and not all facets were covered in the examples documented, the examples collated helped illustrate the significant spectrum of options at various scales being implemented internationally at the time. Only a few of the examples documented were actually being trialled or implemented in Australia in 2017. Those related to AD treatment involving food waste with other organics, commonly practiced in larger systems in many countries, were notably absent in Australia.

In 2019, the collated options were subsequently expanded in the IWC case study into an inventory including over 50 examples and multiple additional sub-examples. The more recent search highlighted the significant increase in both local and international examples being implemented at a range of scales (refer to Appendix E). The inventory purposefully identified options that, while novel, are actually being implemented to give confidence to stakeholders that such solutions are viable and could potentially be trialled and/or implemented in the Australian context. The inventory also included a number of examples of emerging innovation at the initial stage. This was important to include, as planning horizons of 20 years or more are commonly used in resource planning.

The two separate grey literature searches (2017 and 2019) illustrate the rapid rise in innovation in just two years. The IRP and systems thinking divergent thinking of potential options and the sustainability transitions futures and innovation focus was important to expand practitioners' knowledge on what was feasible and on the horizon. This also helping to limit LTS lock-in, and innovation and adaptive management lock-out. Lack of innovation and the use of old technologies was a concern raised by practitioners when consulted about the Sydney context (Turner et al., 2019).

8.1.1.2 MAPPING & WORKSHOPPING OPTIONS DEVELOPMENT

The options development phase in each case study reflected on the specific context being examined, as identified as important by Spang et al. (2019) and a particular strength of IRP practice. This due to the active linkage of options development with the broad and specific context analysis (i.e. IRP Steps 1 and 2). Again, this was notably absent in many other planning approaches. The options development process was expanded in the PUP and IWC case studies through the use of geospatial mapping and visualisation, as advocated by Asefi et al. (2020). This providing an opportunity to improve the understanding of complex waste management systems and associated decision-making. In the case studies this was conducted through both detailed options mapping and options workshopping.

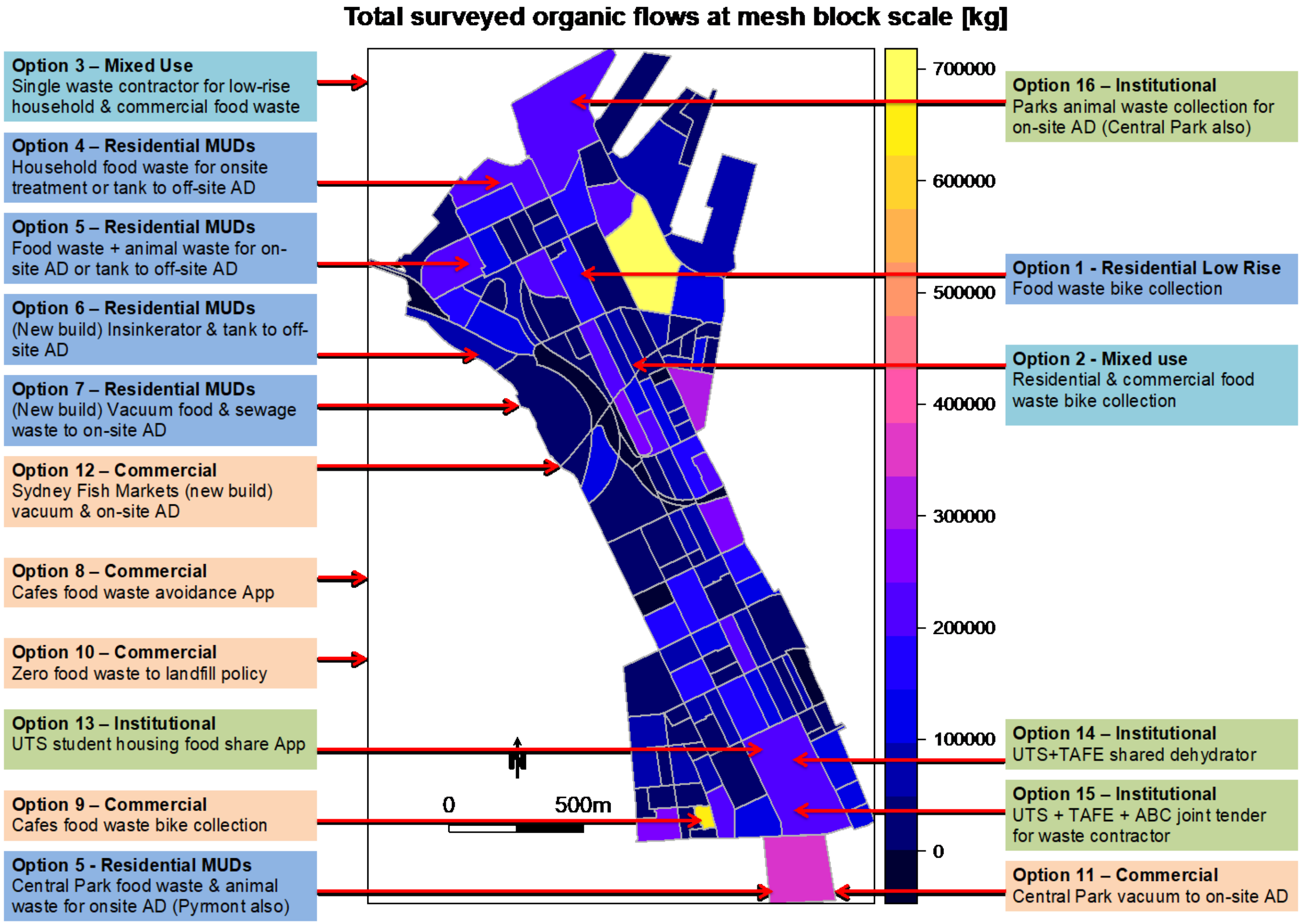
The level of granular geospatial exploration conducted in the case studies is not practiced for UOW management in Sydney or Australia, and, again, appears limited internationally.

Based on the PUP vignettes and IWC options inventory, two different methods of options development were employed in 2017 and 2019, respectively. Both relied on the disaggregated data and insights as well as geospatial maps developed as part of the prior detailed analysis (i.e. IRP Step 2), discussed in Section 7.0.

In the first method, in the 2017 PUP case study, the detailed options mapping and development was conducted by an individual researcher (i.e. myself). This conducted by examining the tons of different UOW streams, geospatial organics intensity hotspot maps, the option vignettes, and detailed knowledge of the demographics and characteristics of the area. For example, where particular options might make most sense due to the detailed context of the area this was identified (e.g. existing low-rise SUDs with a garden versus high-rise MUDs or concentrations of small-scale commercial cafes versus large mixed-use building/precinct scale developments). The PUP sub-LGA is only 1.6 km2 but was the densest urban area in Australia at the time. The exercise aimed to locate a spectrum of 'illustrative' options for subsequent discussion with stakeholders interested in innovative organics management and potentially trialling innovative UOW solutions within the area and/or Sydney. The research and approach used for the final workshop with stakeholders influenced by the 'arena' approach used in sustainability transitions (Loorbach & Rotmans, 2010).

Figure 8.1 shows the output of the options development exercise with a total of sixteen illustrative options generated related to low- and high- rise residential dwellings, commercial and institutional properties, and mixed-use building/precinct scale properties both new and planned. The options also covered a range of technologies, from simple but novel food waste bike collection for local composting to more technology focused on-site vacuum collection and AD treatment systems (i.e. what eventually became the CP case study in 2018). Even an app to find reduced-cost surplus food from local cafes near closing time was illustrated (i.e. an approach now implemented in various cities across Australia and internationally).

Figure 8.1 – Potential locations for illustrative options



(Source: Turner et al., 2017)

In the second method, used in the IWC case study, the options inventory was used in combination with the geospatial maps created (i.e. intensity hotspot as well as asset overlay maps as discussed in Section 7.3). This time, however, relevant IWC staff were engaged in the process of choosing and locating potential illustrative options in their LGA due to their detailed contextual knowledge of the area being examined. The IWC LGA was considerably larger than that of the PUP sub-LGA (i.e. the PUP sub-LGA is only 5% of the IWC LGA) and indicative of the benefits of using local stakeholder knowledge.

To assist IWC staff in engaging with a broad suite of options and consider what options might work best for the IWC context (and ultimately decide the options to take forward for further analysis and costing as part of the options assessment process), the research team facilitated a workshop with fifteen diverse IWC staff. Before the workshop, staff were provided with a briefing paper containing the options inventory and background material. In the workshop, an overview of the project being conducted and its aims and initial findings was provided along with key IRP/systems thinking concepts on the facets of potential options. This was then followed by interactive sessions, which helped participants:

- reflect on their own experience of innovative UOW management, both within IWC but also when working with other organisations and at home/within their community
- discuss on three separate tables (residential, non-residential and institutional)
    - the top three options that would work well in the IWC LGA and why
    - the most non-desirable options and why
    - any additional options not listed in the inventory provided and why added
    - specific barriers, opportunities, alignment with objectives and criteria that needed to be considered.

Appendix D provides a summary of the workshop process and findings. Figure 8.2 illustrates options playing cards, used to assist with engagement and to stimulate table discussions. Figure 8.3 shows the resulting 'illustrative' options mapped on an organics intensity hotspot map together with criteria, barriers, opportunities, potential timelines and strategy alignment for the residential table discussions. The options inventory, playing cards and how the discussion tables were set out explicitly aimed to help participants consider a broad suite of options (divergent thinking), many beyond IWC current control (i.e. cafes, hotels and schools) in the non-residential and institutional sectors. Feedback on the workshops by participants highlighted the benefits of drawing together diverse groups within the council with significant knowledge to help think through possible options.

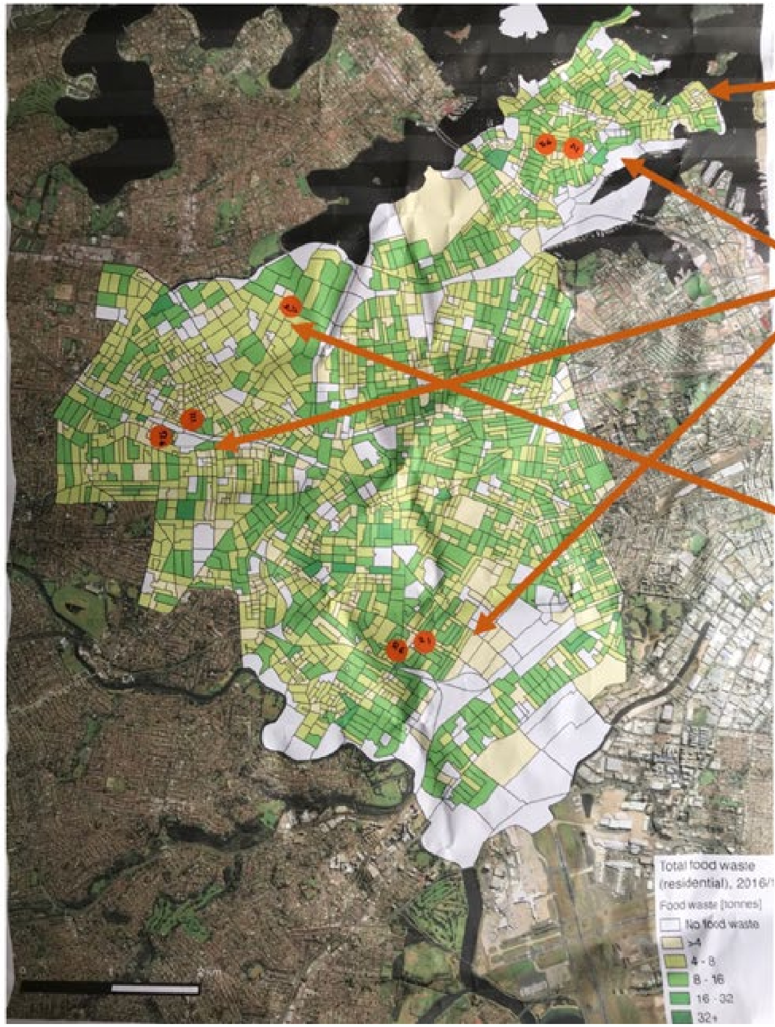
Figure 8.2 – Option playing cards

(Source Jazbec et al., 2020b. Reproduced with permission of authors and client)

Figure 8.3 – Outputs from residential table discussions

Option playing cards used to identify sites for implementing options in the LGA

R-1 - compost revolution
R-2 – Home dehydrator
R-3 – Community garden
R-4 – Sharewaste
R-5 – PAYT
R-6 – FOO MUDs collection
R-7 – FOGO SUDs collection
R-8 – In-sink-erators to off-site AD



Options mapping

OPTION 1 – based on R-5 – PAYT
Across IWC

OPTION 2 – based on R-1 – Compost Revolution
For SUDs across IWC (excluding Haberfield area)

OPTION 3 – based on R-6 – FOO MUDs
For MUDs across IWC

Also, R-7– FOGO SUDs should be considered for area in Haberfield with large SUDs

TOP 3 OPTIONS

	Option 1 - PAYT	Option 2 – Compost	Option 3 - FOO
Reasons & criteria	• Encourages waste avoidance • Behaviour change through financial incentive • Encourages responsible behaviour/for own waste • Economic driver for council	• localised processing • low cost + low resources • proven reduction - good diversion rate • flow on behaviour change benefits	• Demand for food as a resource/markets • Impact on food waste reduction in red bin • Build on experience in LH/proof of concept • Lack of garden organics in 2/3 of LGA • Grant money • End facility secured
Barriers	• Social acceptance • Littering • Infrastructure locations/where • Transition to new system	• Yuck factor • Poor management • Lack of space • High level of resident effort (perceived)	• Limited to MUDs due to extra bin • Cost of compostable bags • Yuk factor (perceived smells/pests) • Cost • Resourcing
Opportunities	• Significant opportunity to focus/address waste avoidance • Reduction in heavy vehicle movements • Revolutionise waste collection	• Local use of end product • Soil improvement • Low council effort/pay-off for small input • Links to web based communities & community gardens	• Grant • Clean food waste stream • Ease of use/familiar infrastructure
Timeline	• Transition period needed o long	• Soon/now	• soon
Strategy alignment	• zero waste community	• Zero waste	• zero waste • circular economy

NON-DESIRABLE

Option 4	In-sink-erators to off-site AD
Reasons and criteria	• High use of water - high cost in relation to ecologically sustainable development (ESD) • Infrastructure? • End product would go to the ocean, currently
Barriers	• Not environmentally friendly in local environmental conditions • Set up costs • Unknown technology
Opportunities	

ADDITIONAL

Option 5	Drop-off programs (e.g. compost huts)
Reasons and criteria	• There is intent/desire • Builds social capital • Empowerment • Starting to move towards drop-off culture
Barriers	• Resourcing • Overload • End-use • What do we do with material
Opportunities	• Proof of concept

(Adapted from Jazbec et al., 2020b. Reproduced with permission of authors and client)

8.1.2 BROADER IMPLICATIONS

Avoidance and smaller-scale on-site demand-side solutions are advocated and are being implemented in NSW and more generally. However, they are ad hoc. They are also not implemented at scale, and despite knowledge on potential options growing, overall knowledge of the vast array of demand and supply-side options available and being implemented internationally, as well as their positive and negative cross-sectoral impacts, is limited. The case study examples of using IRP methods to systematically use divergent thinking to identify options and subsequent context-focused thinking, supported by new mapping and workshopping methods, provide significant opportunities. This is to both open up the selection of options available to stakeholders and enable them to engage. Such divergent and context-focused thinking currently appears to be missing in waste management planning and thus limiting the potential of avoidance and demand-side options.

Despite the waste hierarchy dominating waste management for decades and prioritising avoidance, it is still under-represented, and more focus is put on avoidance from landfill rather than avoidance from generation. With the shift in policy in NSW and Australia advocating avoidance and higher-order circular economy outcomes for organics, there is real potential for a variety of scales of demand-side solutions to flourish. However, there is also a risk of jumping to more traditional lower-order recycling LTS solutions due to the tension emerging between avoidance, on-site systems and LTS composting. This is especially the case with the current fragmented management of UOW, the dominance of the private industry, and policy mandating prescriptive LTS FOGO, which may limit other effective treatment of organics including various scales of AD.

The practical IRP augmented methods demonstrated in the case studies can provide key stakeholders (such as councils and regional groups of councils such as SSROC) with structured methods to enable them to consider a far broader selection of context-relevant options for their areas. These include options currently outside their control. It can also assist those at the mixed-use building/precinct scale to think beyond LTS collection. This helps to break the reliance on LTS silver bullet solutions and the dominance of the private industry. To aid practitioners further, federal and state government leadership is needed to provide access to transparent, up-to-date collated knowledge on the potential options being implemented internationally at various scales and their potential cross-sectoral benefits and unintended impacts as the NSW Government has recently done for water efficiency (Watson et al., 2020). This would assist in centralised knowledge-sharing and avoid duplication of research.

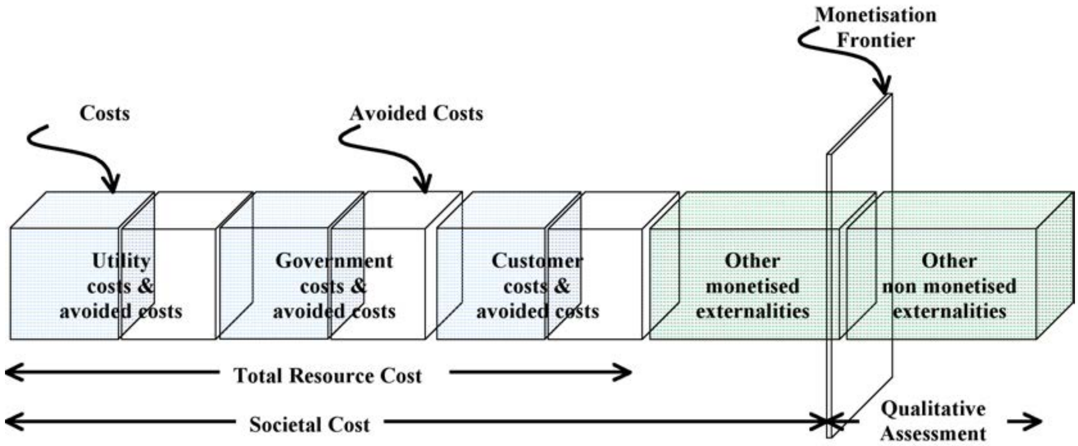
8.2 COSTING AND ASSESSING OPTIONS

While the gaps and opportunities in Section 2.5 do not explicitly identify costing as a gap or opportunity, it does illustrates the bias of the assessment methods used for options which can have a large impact (i.e. economic or financial in terms of CBA and environmental in terms of the waste hierarchy and LCA). Hence the need for planning approaches to consider the objectives and criteria from multiple perspectives, as advocated by Mourad (2016) for food waste, and the incorporation of MCDA features that transparently and effectively consider the costs and benefits and broader social and environmental perspectives of demand- and supply-side options.

A key strength of IRP is the fair comparison of options between demand- and supply-side solutions, using consistent boundaries and assumptions with the data available. It seems an obvious requirement, yet historically in water, such 'fair' comparison was often not conducted. Historically, options were often considered by different departments within an organisation with different assumptions and even costing techniques. However, there are now many examples in water IRP of considering options within the same IRP assessment framework and the comparison of demand-side options to achieve an efficiency target or demand- and supply-side options to fill an emerging supply-demand gap (Turner et al., 2010a; 2016), that is, whatever the core objective/s being examined. Such analysis aiming to select a suite of options at the lowest cost but highest benefit to society using CEA. As well as examples aimed at efficiency or supply-demand objectives, there are also examples that illustrate other important objectives. These include, as mentioned in Section 6.4, the reduction of peak water demand (to optimise the existing system), reduction in wastewater production (to minimise treatment needs/overflow pollution) and reduction in energy intensity of water service provision (see the study on Alice Springs by Turner et al., 2007).

To assist in fair comparisons in water IRP, options are typically considered initially based on whole-of-society costs. That is, not just financial costs incurred by a utility typically implementing the options program, although this is a useful additional assessment (i.e. utility costs). Where possible, costs and avoided costs/monetisable benefits are included for each of the key stakeholders involved (often utility, government, customer) and then other monetised and non-monetisable externalities. Non-monetisable externalities are incorporated using qualitative assessment techniques to allow comparison (i.e. other MCDA objectives and criteria). Figure 8.5 illustrates the spectrum of costs, benefits and externalities considered.

Figure 8.5 – Disaggregated costs, avoided costs and externalities



(Adapted from Turner et al., 2010a)

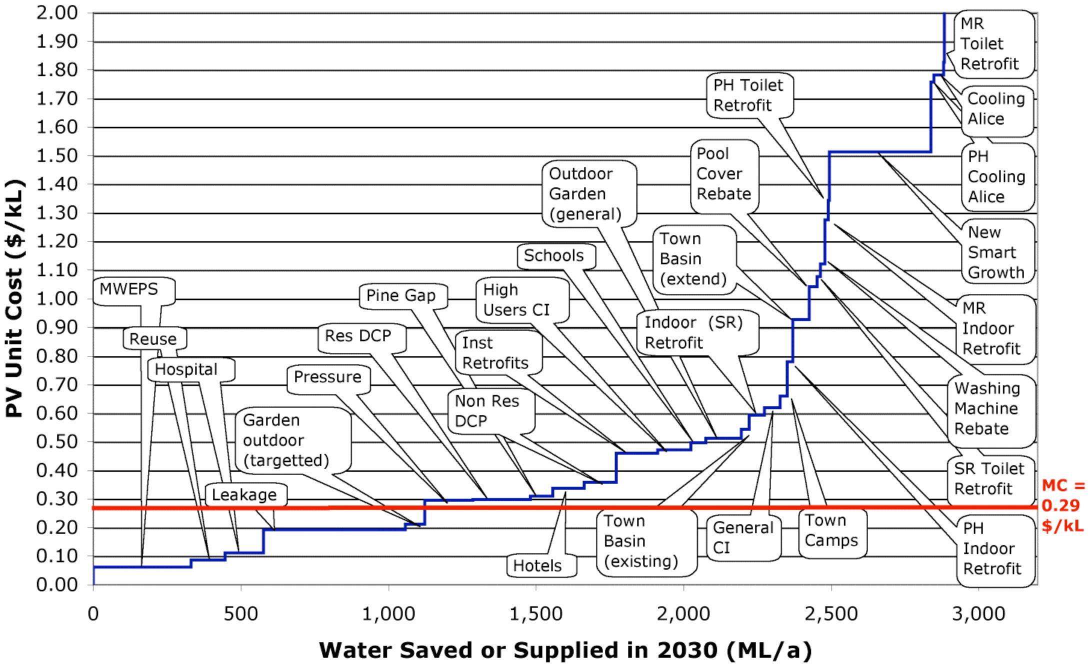
Often demand-side options are the most cost effective when compared to supply-side options, even without incorporating the significant additional benefits (i.e. reduction in energy bills for customers due to hot water savings from efficient showerheads). Table 8.1 shows a typical historical example of a costs and benefits table used in water IRP with options initially ranked by unit cost (i.e. $/kl saved or supplied) along with total PV costs of the options and then a selection of costed benefits (i.e. water, sewage, GHG and energy). Figure 8.6 shows typical supply curve ranking options (on whole-of-society costs before benefits are incorporated) to illustrate the lowest cost options and their contribution to water savings or supply in a target year. Similar supply curves are generated including costed benefits.

Table 8.1 – Example of ranked options costs and benefits table

Initial No.	Options	Option Total Cost PV$	Unit Cost PV$/PVkL	Ranked No.	(A) Water Saving Benefits (Utility) PV$	(B) Sewage Saving Benefits (Utility) PV$	(C) GHG Saving Benefits (Utility) PV$	(D) GHG Saving Benefits (Customer) PV$	(E) Energy Saving Benefits (Customer) PV$
23	MWEPS	43,978	0.06	1	189,575	24,888	24,029	73,009	398,209
31	Reuse	88,060	0.09	2	253,673	-	28,716	-	-
19	Hospital Program	141,472	0.11	3	317,212	29,156	40,815	85,530	466,503
21	Leakage program	779,404	0.19	4	1,008,726	-	114,585	-	-
9	Garden outdoor (high user targetted) pro	129,980	0.21	5	152,273	-	17,307	-	-
22	Pressure Reduction	451,489	0.30	7	380,018	-	43,192	-	-
24	Residential DCP	161,971	0.30	6	142,943	3,414	15,890	12,519	68,280
13	Pine Gap (SR) program	230,661	0.31	8	184,602	7,831	22,302	28,716	156,625
17	Hotel program	305,514	0.34	9	226,526	18,183	28,437	66,673	363,653
25	Non-Residential DCP	103,781	0.36	10	76,472	3,041	8,661	4,461	24,330
18	Institutional retrofit	522,105	0.46	11	285,367	19,880	35,232	58,319	318,085
16	High Users C/I water efficiency program	454,326	0.47	12	240,907	10,105	28,777	14,821	80,840
20	Schools Program	230,696	0.50	13	115,440	6,763	14,194	9,919	54,101
8	Outdoor Garden (SR general) program	501,050	0.51	14	246,082	-	27,660	-	-
29	Town Basin (existing)	124,238	0.54	15	56,963	-	6,448	-	-
1	Indoor (SR) retrofit program	278,684	0.59	16	117,044	16,433	15,865	60,256	328,653
15	General C/I water efficiency program	240,783	0.62	17	98,409	4,083	11,626	5,988	32,660
14	Town Camps Program	133,514	0.66	18	50,618	3,539	6,271	5,190	28,309
6	Public housing indoor retrofit	133,108	0.78	19	42,413	5,976	5,769	21,912	119,512
30	Town Basin (extend)	461,691	0.93	20	124,382	-	14,080	-	-
10	Pool cover rebate	227,497	1.04	21	54,864	-	6,167	-	-
3	Indoor (SR) toilet retrofit program	102,790	1.08	22	23,819	3,344	3,229	-	-
5	Washing Machine Rebate	142,033	1.12	23	31,839	4,436	4,283	13,013	70,979
2	Indoor (MR) retrofit program	134,789	1.27	24	26,357	3,700	3,573	13,569	74,008
7	Public housing toilet retrofit	47,241	1.34	25	8,742	1,232	1,189	-	-
26	New Smart growth	1,241,031	1.51	26	218,085	7,179	24,304	26,323	143,572
12	Cooling Alice Public Housing program	135,558	1.76	27	19,311	-	2,178	-	-
11	Cooling Alice residential program	489,408	1.78	28	68,993	-	7,755	-	-
4	Indoor (MR) toilet retrofit program	40,510	1.83	29	5,529	776	750	-	-
28	Greywater rebate (existing SR)	2,308,231	7.91	30	73,264	13,781	10,423	-	-
27	Rainwater tank rebate (existing SR)	2,512,430	21.54	31	29,306	-	3,294	-	-
	Totals	12,898,023			4,869,754	187,739	577,002	500,218	2,728,319

(Source: Turner et al., 2007)

Figure 8.6 - Example of a supply curve of ranked options



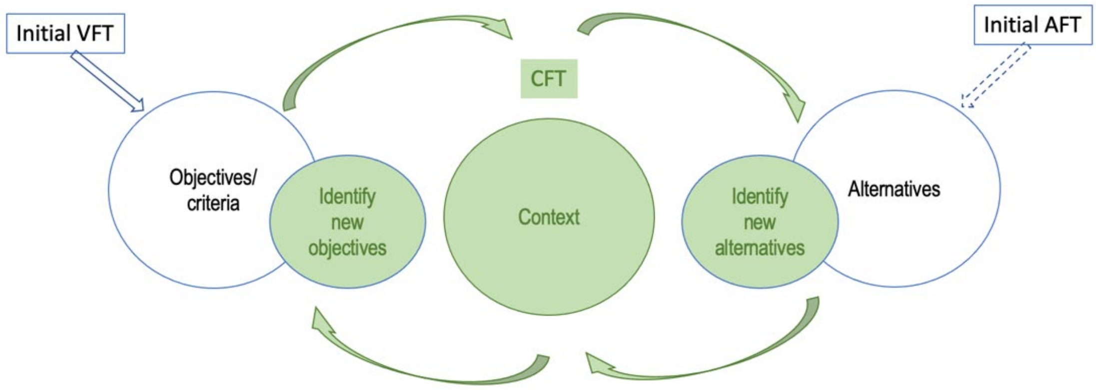
(Source: Turner et al., 2007)

In the case of UOW in Australia, firstly, until recently, options considered have typically only centred around a single organic option within a mix of broader waste management options aiming to avoid materials passing to landfill and associated overall landfill diversion targets.

Secondly, when organic options have been considered they have typically only included a limited number of streams, such as residential food waste in red bins and garden organics (i.e. the responsibility of the local metro councils). Thirdly, such options have typically been considered from the council's perspective and have not included whole-of-society costs (i.e. the customer cost contribution of buying equipment such as compost bins) nor extended monetisable and non-monetisable benefits (i.e. capturing nutrients). There will, of course, be some non-public examples which may have more breadth. However, with the new focus in waste management now specifically including 'organics' targets since the release of the new waste strategy (NSW DPIE, 2021a), greater emphasis is now needed on costing and assessing multiple streams of UOW for multiple scales of options from multiple perspectives for different jurisdictions. Such analysis is currently complicated due to the drive for LTS FOGO services, which may or may not be the most cost-effective option nor achieve desired objectives. For example, while FOGO is potentially capturing nutrients and aiding landfill diversion, it is not achieving food waste avoidance at source nor potential energy generation and GHG reduction.

The tension generated by the need to prioritise avoidance at source while prescriptive policy is driving lower-order LTS FOGO, highlights the importance of clear objectives and criteria in UOW planning. These tensions are exacerbated, as discussed in Section 6.4, by the gradual shifting of objectives for organic waste over recent years in Australia due to the significant changes in waste management policy. Hence, now more than ever, there is a need to use MCDA methods to elucidate clear objectives to work towards and criteria to effectively assess options against. However, as discussed in Section 2.3.6, this should not solely come from a value focused thinking perspective nor a traditional alternative focused thinking perspective but a combination of MCDA and IRP methods. That is, iterative value-context-alternatives focused thinking (within IRP Steps 1, 2 and 3) as illustrated in Figure 8.7, where objectives and alternatives are considered dynamically with the context through the IRP process, especially in IRP Step 3.

Figure 8.7 – Iterative value-context-alternative focused thinking for decision-making



(Adapted from Corner et al., 2001)

This tension between options also raises questions about what objectives and criteria are used and how options are assessed and selected for piloting and full implementation. Also, importantly, who makes those decisions in practice. MCDA is an obvious method to assist in decision-making, however, overriding 'power', as identified in third-wave systems thinking, is an important additional feature that needs to be considered. This issue is especially important in the fragmented waste management industry with such strong private industry dominance and now prescriptive policy intervention.

8.2.1 CASE STUDY EXAMPLES

Two groups of methods were considered, as far as possible, in the case studies:

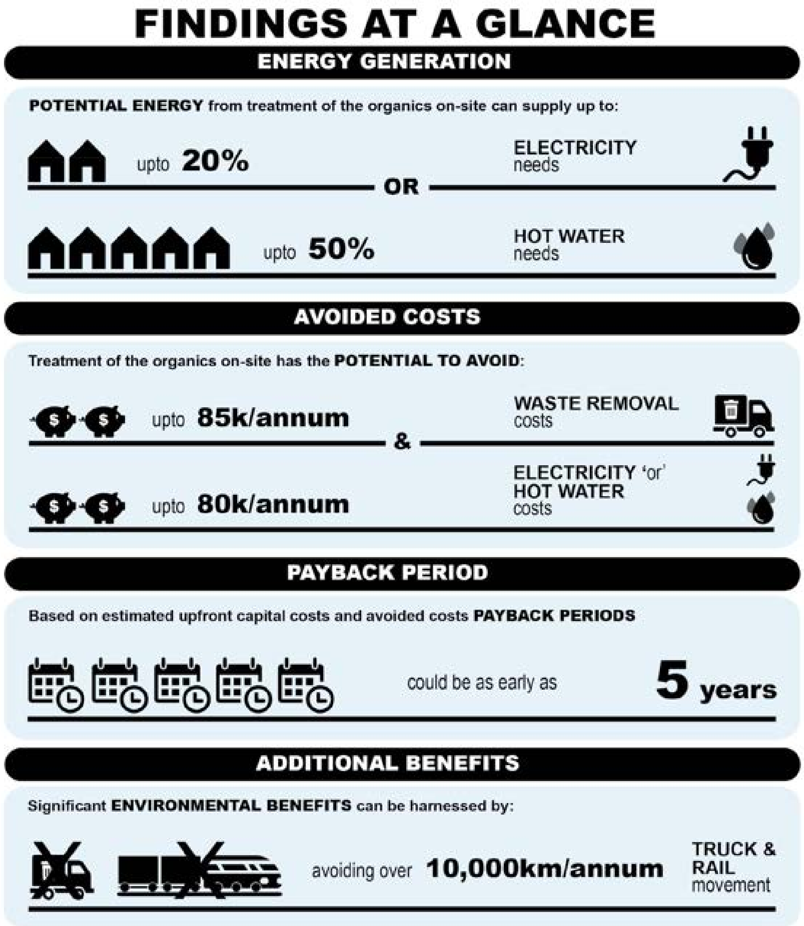
- avoidance and costing and benefits analysis
- objectives and criteria assessment.

8.2.1.1 AVOIDANCE & COSTING & BENEFITS ANALYSIS

While the PUP case study did not consider analysis of costs and benefits, both the CP and IWC case studies did. The CP case study focused on the high-level costs and benefits at a single building/precinct scale, while the IWC case study looked at an entire LGA. Both case studies were novel in terms of looking at particular scales, a variety of UOW streams and an array of options, including AD; this type of analysis absent in the Australian waste management context.

In the CP case study, due to the limited scope of the project, the options were confined to a narrow selection of collection methods, but included novel vacuum systems, various UOW streams and the use of AD as an on-site treatment process to generate bioenergy. Overall findings are illustrated in Figure 8.8, showing the potential benefits of on-site collection and treatment (i.e. savings on avoided waste removal, electricity or hot water savings, significant savings in transport). Upfront capital costs were as low as AUD 500,000, depending on the option. The case study ruled out retrofitting of vacuum systems for collection of food waste due to the high capital costs but identified significant opportunities if such technology was incorporated at the design and construction stages, as would be expected.

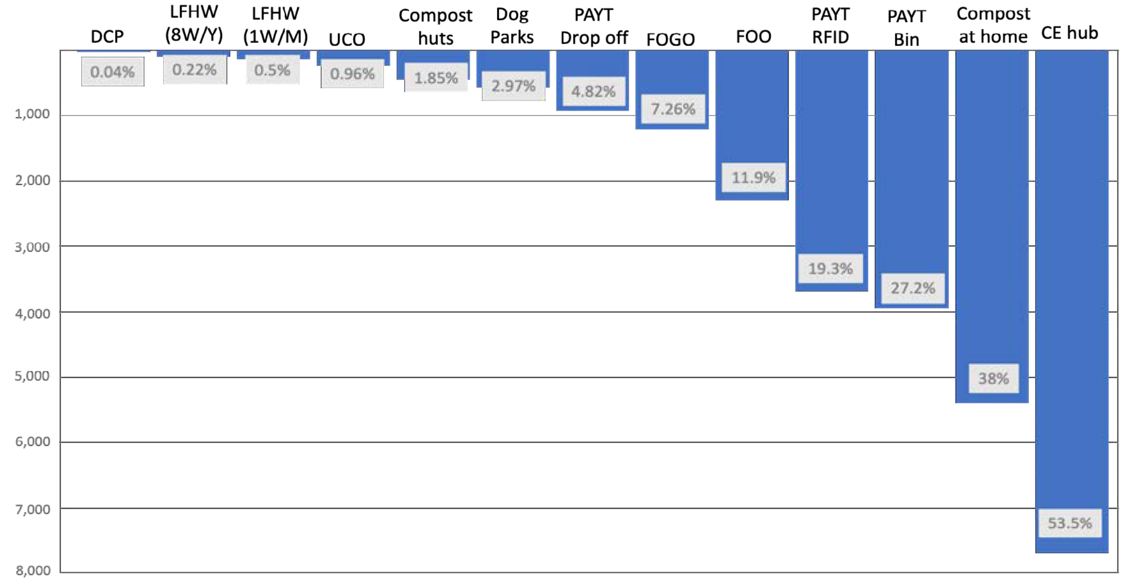
Figure 8.8 – Summary of findings



(Source: Turner et al., 2018)

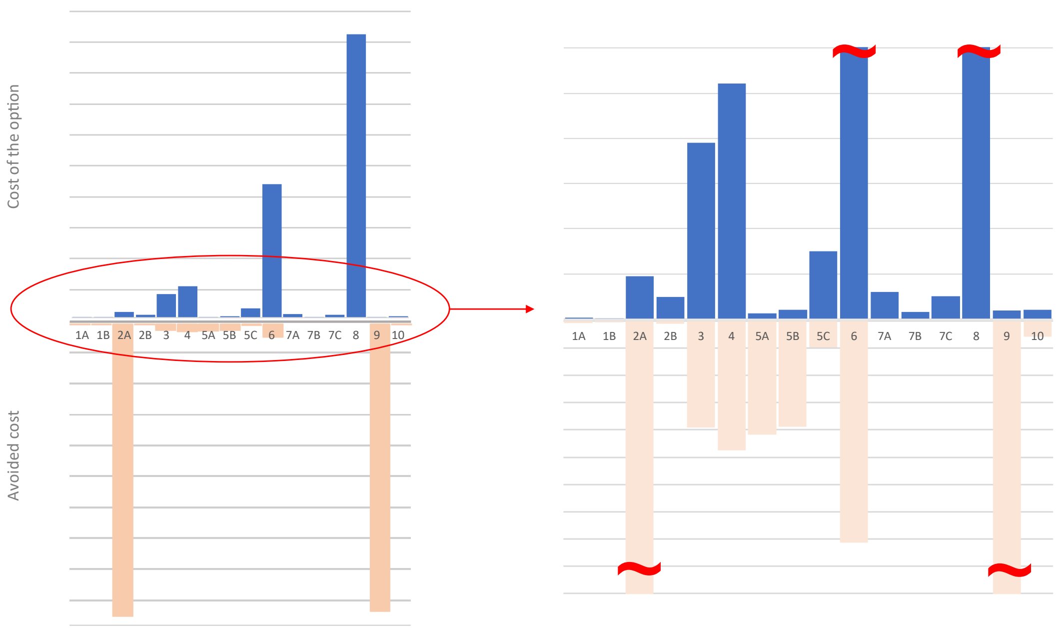
The IWC case study was initially intended to be used to conduct a full assessment of options based on transparent IRP practice and to make the final project report public. However, due to various circumstances such as major restructuring of the council executive team and decisions on which organics options should be progressed made above the waste management team, this did not eventuate. Hence, only illustrative options and partial aspects of avoidance, costs and benefits analysis were eventually conducted. Limited and restricted result, which are in the public domain, are shown here. Full details are provided in Appendix D. A total of sixteen options and sub-options were developed for illustrative purposes following the options development workshop discussed in Section 8.1.1. These ranged from composting at home, communal compost huts and local used cooking oil depots, to food-only collection for MUDs and FOGO services for SUDs. The options even included a council-focused circular economy hub for multiple UOW streams using council assets and the use of development control plans for new precinct scale developments. The analysis included, with the data available, assessment of the potential avoidance and/or diversion from landfill of the spectrum of potential options of various scales (see Figure 8.9). It also included assessments of the costs and benefits for both council (see Figures 8.10) and other stakeholders.

Figure 8.9 - Organics diverted from landfill (tons & percentage for individual options)



(Source: Jazbec et al., 2020a. Reproduced with permission of authors and client)

Figure 8.10 - Options relative cost & avoided costs from the council's perspective



1A – Love food hate waste (LFHW) - 1 week/month	avoidance		6 – Circular economy (CE) Hub	Processing organics within IWC
1B – Love food hate waste - 8 weeks/year			7A – Com on site	Processing commercial organics within the LGA
2A – Compost at home	compost		7B – Com garden	
2B – Compost huts			7C – Used cooking oil	
3 – Food organics only (FOO)	in MUDs		8 - IWC assets	Manage at IWC sites
4 - FOGO	in SUDs		9 – Development control plans (DCP)	Use of DCP in new precinct developments
5B - PAYT – RFID	Pay as you throw		10 - Dog park waste	
5C – PAYT – drop off				

(Source: Jazbec, 2021. Reproduced with permission of authors and client)

While the costs and benefits of options are highly dependent on the option design and uptake, the analysis of costs and benefits conducted highlighted the significant benefits and potential contribution to landfill avoidance that simple options such as composting at home can provide at a relatively low cost (option 2A). They illustrate the potential cost barrier for council to use their own assets to provide local UOW management (option 8) but potential benefits of focusing on new precincts through development control plans (option 9).

However, when looking at broader whole-of-society costs and benefits, the options and unit cost ranking picture begin to change as shown in Table 8.2. For example, composting at home (option 2A) remains one of the best options in terms of unit costs (i.e. positive overall benefits to society). However, pilot programs already implemented, such as communal compost huts (option 2B), the Development Control Plan for new precincts (option 9) and the FOGO option for SUDs (option 4) are the highest unit cost options (i.e. negative overall benefits to society) as the additional costs and benefits of other stakeholders are included. This illustrates the importance of garnering the various resource savings, costs and benefits for various stakeholders involved. This is commonly practiced in IRP to help decision-makers better understand various aspects of the options available. In this way, by considering the costs and benefits from a whole-of-society perspective (i.e. beyond financial), this enables transparent discussion among key stakeholders and the opportunity of cost sharing to achieve the most cost effective outcomes for society.

Table 8.2 – Options net present value unit cost ranking based on whole of society costs & benefits

Positive	Negative
1 – Food waste avoidance	7B – Commercial community garden
6 - Circular economy hub	5B – Pay as you throw RFID
7C – Used cooking oil	8 – IWC assets
2A – Compost at home	3 – Food only organics
5A – Pay as you throw bin size	5C – Pay as you throw drop off
7A – Commercial on site	2B Compost huts
10 – Dog waste park	9 – Development control plans
	4 - FOGO

(Adapted from Jazbec et al., 2021. Reproduced with permission of authors and client)

8.2.1.2 OBJECTIVES AND CRITERIA ASSESSMENT

Due to the major restructuring of the council executive team and shifting priorities, the timing of the IWC case study did not align with the development of the IWC Waste Strategy, which was delayed until later in 2021 (IWC, 2021). Hence, as discussed in Section 6.4.1, this meant when looking at objectives for the IWC Options Workshop, broader objectives had to be used. These broader objectives were difficult to use in practice and highlighted the importance of garnering specific objectives relating to organics at the commencement of a planning exercise, which could then be reassessed as part of the options development and assessment stages. Whilst the objectives were limited they were used to assist developing the options during the breakout table discussions in the workshop using the geospatial maps provided (i.e. iterative value-context-alternatives focused thinking).

Due to the absence of specific organics related objectives, as part of the IWC Options Workshop, participants were asked during discussions to identify what kinds of issues might need to be considered when developing and assessing options for their area. They were also asked how they may have made decisions on such options or pilots studies in the past, at IWC or in other previous council positions. This surfaced a significant number of issues well beyond the typical financial/economic criteria that often dominate decision-making. The issues were converted to a series of questions and filtered into themes through a PESTLE framework. Whilst not used in the IWC case study the questions are useful in helping to develop organics related objectives and criteria. They also help highlight the broad array of issues that need to be considered by councils, including factors such as power as identified in third wave systems thinking, yet do not have practical tools to do so.

Table 8.3 – Issues raised during the IWC workshop converted into questions and filtered through a PESTLE framework

Political/Legal	Economic (business)
Is there alignment with national, state and/or local policy/requirements	What is the total economic cost ($)
Is there uncertainty over policy	What is the unit cost ($/t avoided from landfill)
Is there alignment with IWC strategies	How do the unit costs compare to BAU
Is there alignment with local IWC plans (i.e. PoM 10 year)	Who pays (IWC financial cost/others costs)
Is there a Mayor/Councillors/GM motion/request and/or buy-in	Who benefits (IWC financial gain/others gain)
Is there internal IWC buy-in incl' asset owners/managers	What is the scale of cost (total/IWC financial/others)
Is there external buy-in incl' asset owners	How are the costs distributed (upfront/over time)
Is there a need to change DCPs	Are funds available (now/later)
Is there a need to change waste management plans	Are grants available (now/later) and at what scale
Is there compliance with regulations (e.g. EPA) incl' outputs	What are the business needs
Do external approvals/timing need to be considered (e.g. strata)	Does the business model incl' partnering and/or outsourcing
	Is there a risk of a black market being created
Social	**Technical/Innovation**
What are the total resources needed (IWC/other) incl' reliance on volunteers	Is infrastructure available/end facility secured
What is the level of community acceptance/request/momentum/action	Is it technically feasible
Are there community/IWC champions	Is it a proven technology/approach
What is the level of community/IWC effort needed	Are there existing precedents
Will it demonstrate desired norms and help change behaviour/norms	Will it assist in proof of concept and/or help test/demonstrate for other sites
Will it have a flow on effect	Can it fill gaps in knowledge
Will it empower the community	Is there space available or are there constraints
Will it build on business/community social capital/networks/cohesion	Are there building stock constraints
Will it build on IWC knowledge/experience	Are there construction issues/constraints
Will it link to other initiatives	Are there potential maintenance issues
What is the ease of use/level of familiarity with the infrastructure/approach	Does it add to and/or integrate with existing processes and management
To what extent will it align/require change in practices	What is the extent of change required
What is the level of sector access/inclusion	Is the timing for implementation appropriate (e.g. technology enabled)
Will transient populations be involved	
Environmental	**Combined/Other**
Does it encourage avoidance	Is it sustainable over time
Does it provide effective volume avoidance/reduction of waste	To what extent does it assist sustainable waste management transition
Are the volumes too large to manage	Does it incorporate CE principles
What is the water/energy usage	Does it encourage reuse of wasted materials at a higher CE value
What is the energy generation	Can it take advantage of the local context
Does it affect GHGs	Can it use/take advantage of local council land and/or assets
Is there loss of resources/nutrients	Are ther competing uses for land and/or output
Is there nutrient/biosolids capture	Does it encourage local processing and/or use
Is there soil improvement	Does it encourage local resources/management/training
Is there potential for littering, smell, pests	Does it impact other industry sectors (i.e. water industry)
Does it affect vehicle movements/distances	Is the waste stream 'clean'
Does it affect traffic flow/constraints	What is the quality of the end product and is there a market for it
Does it affect contaminated land	Is there consistent and/or sufficient input to meet end product demand
	Does it affect heritage sites
	Is evaluation embedded in the process

8.2.2 BROADER IMPLICATIONS

Progressive councils such as the IWC have piloted and implemented a number of innovative UOW solutions. However, current tools to assist in decision-making are limited and do not adequately address the broad array of objectives and criteria that need to be taken into consideration in practice, as highlighted in the IWC Options Workshop. Such objectives and criteria well beyond the narrow financial perspective that tends to dominate decision-making, which can still be overridden by councillor's decisions in practice (i.e. dominant power as identified in third-wave systems thinking).

While advanced assessment methods may have been used in IRP, and there are highly sophisticated options assessment methods based on MCDA theory these need to be translated into practice for UOW planning. They also importantly need to involve multiple stakeholders and iteration between identification of objectives, the context and potential options (i.e. value-context-alternatives focused thinking), a strength of IRP. The assessment of UOW options and ways to develop effective practical decision-making incorporating MCDA is an important area of research needed. This particularly the case in Sydney, while councils respond to the new cross sectoral policy targets and need to decide on options which may have long-term contracts implications.

The next section provides a summary of the research contributions, limitations, conclusions and potential next steps. It also provides an overview of the elements of a potential UOW IRP framework that could be developed for future use over the coming years in Sydney and similar dense urban environments.

PART V:

SYNTHESIS OF RESEARCH, CONTRIBUTIONS, CONCLUSIONS & NEXT STEPS

9 CONTRIBUTIONS, CONCLUSIONS & NEXT STEPS

9.1 INTRODUCTION

In this thesis, I have focused not just on food waste, a major issue causing significant concern globally in terms of wasted resources and sustainability impacts, but on the less explored and broader UOW management problem. To explore this problem, I used the largest city in Australia as a case study. I used Sydney not only because it represents a city undergoing rapid growth and densification that is causing waste management issues also experienced in many other developed countries, but also because of the acknowledged need to improve UOW management within the city. This need was recently demonstrated through various major shifts in government waste management policy and funding as well as industry discourse and investigations, as discussed in Section 1.2.

In addressing the three overarching research questions identified in section 1.3.2, namely:

- What are the gaps and opportunities in UOW management planning?
- How can this be strengthened in theory and practice through systems thinking, sustainability transition management and IRP?
- What insights can be drawn from the water sector given the similarities and differences between water and waste and the associated sectors?

this thesis has focused on three core areas:

- **at a theoretical level:** I have conducted a **comparative meta-analysis of IRP**, between water and UOW, allowing me to illustrate how IRP, strengthened by systems thinking and sustainability transitions, assists in filling identified gaps and opportunities in UOW management planning, analysis and decision-making, despite data paucity and fragmented management.
- **at a detailed level:** I have used a series of **nested case studies within Sydney to fill identified waste management industry knowledge gaps** centring around quantifying UOW streams, analysing stakeholders and identifying relevant internationally inspired socio-technical UOW management solutions at various scales.
- **at a practical level:** I have identified and tested **a variety of methods to use in future IRP practice**, explored through the case studies, specifically for UOW but also potentially water IRP to further improve its application.

Hence, the research makes contributions by (i) strengthening IRP at a theoretical level including greater linkage with systems thinking and sustainability transitions, (ii) filling specific UOW sector knowledge gaps for Sydney, which have the potential to be used in other dense urban settings, and (iii) advancing IRP at a practical method level specifically for UOW.

Table 9.1 builds on Table 3.5 (Section 3.5) and provides a summary for Sections 9.2.1 focusing on theory and 9.2.3 focusing on practical methods. Specifically the table identifies the:

- gaps and opportunities, elucidated in Section 2.0
- core IRP steps that have the potential to respond to those gaps and opportunities and their existing strength to do so based on water experience, as discussed in Section 3.0
- opportunity to augment IRP with systems thinking and/or sustainability transitions concepts and methods, also discussed in Section 3.0
- specific methods from IRP, systems thinking and sustainability transitions tested on the Sydney-based nested case studies summarised in Sections 4.0 and 5.0
- extent to which those methods could be tested in the research
- whether those methods could be usefully applied not only in UOW but also potentially water IRP in the future.

In the following sections, I synthesise the research conducted, identify my contributions, and highlight potential limitations. I also summarise the elements of a potential UOW framework based on IRP, systems thinking and sustainability transitions concepts and methods, together with final conclusions and suggested next steps for future research and action.

Table 9.1- Summary table of gaps & opportunities, IRP steps & potential novel methods

Waste management planning gaps & opportunities (identified in Section 2)	IRP step & sub-step foci	Existing IRP strength	Potential to strengthen in theory and/or practice with	Potential novel methods to incorporate in practice	Potential future IRP application	
					UOW	Water
A need for approaches that better consider & incorporate: 1. a broader & deeper **socio-technical systems perspective** 2. multiple & often conflicting **objectives** & **criteria** specifically relevant to UOW characteristics 3. the **broad context** of the jurisdiction being investigated & associated **drivers and pressures** 4. **cross-sectoral impacts** & **trade-offs** 5. the diverse **stakeholders** involved in generating & managing UOW to more effectively account for stakeholders & **social perspectives** 6. **MCDA features** that work through objectives & criteria, the specific context & an array of potential solutions **iteratively** (i.e. value-, context- & alternative- focused thinking) 7. the **detailed context** of the jurisdiction to help inform decisions despite **data gaps** 8. a broader **network of complementary options** of varying scales 9. **preservation of resources/prioritisation of avoidance** 10. the risk of **LTS lock-in & adaptive management & innovation lock-out** 11. integration of **GIS/visualisation** techniques to assist in better understanding complex waste management systems & **engage stakeholders** to improve decision-making	**1 – Plan & frame**					
	Define system & boundaries	●●●	Systems thinking	System diagrams & value chains (devices)	√	
	Consider the diverse stakeholders	●	Systems thinking	Stakeholder analysis identification, mapping & motivations investigations	√	√
	Clarify the broad context	●	Sustainability transitions	Transitions model workshopping	√	√
	Identify key service & objectives	●●●	Systems thinking	Objectives/value focused thinking	√	
	2 – Analyse					
	Conduct resource disaggregation	●●●	Systems thinking	Sector disaggregation, data pooling & snapshot insights	√	
	Conduct disaggregated forecasting	●●●	Systems thinking	Factors analysis Disaggregated forecasting	√	
	Conduct mapping & visualisation	-	Systems thinking Sustainability transitions	Intensity hotspot mapping, asset overlay & route mapping	√	√
	3 – Develop & assess					
	Identify & develop options	●●	Systems thinking Sustainability transitions	Options inventory (incl. innovation) & mapping & workshopping	√	√
	Cost and assess options	●●●	Systems thinking	Costs & benefits tables/graphs MCDA objectives/criteria Value-context-alternatives thinking	√	

9.2 RESEARCH SUMMARY & CONTRIBUTIONS

9.2.1 COMPARATIVE META-ANALYSIS OF IRP

IRP is a tried and tested practical approach used extensively for planning in the water and energy essential services sectors. A core aim of this research was to examine at a theoretical level whether the concepts of IRP could be applied to and help improve planning, analysis, and decision-making in the emerging UOW management sector. The examination was conducted through a comparative meta-analysis using water IRP as a heuristic. Table 3.1 provides an overarching comparison and translation of the key IRP concepts from water to waste/UOW and Section 3.5 summarises how systems thinking and sustainability transitions could be used to assist in the application of IRP to UOW. These concepts were further examined using the first three planning steps in IRP, as discussed in Sections 6.0, 7.0 and 8.0 and summarised in Table 9.1.

Overall, the use of IRP concepts works well. In terms of service provision, waste services under NSW legislation are identified as 'essential' as are water and energy where IRP has been applied extensively. Also, waste provides a 'service' not a 'commodity', like water and energy, in line with systems thinking, and if interrupted, the urban environment rapidly begins to suffer. This is due, for example, to the build-up of putrescible materials causing social nuisance, health risks and detriment to the environment. In terms of overall resource planning, UOW needs to be avoided in much the same way as water needs to be used more efficiently and where this is difficult or maximised, then both resources should be reused in a sustainable way. Also, the way the system can be defined by the disaggregated services it provides and viewed in terms of a resource with different end-uses/micro components (in water) or different streams with different potential uses (in UOW), holds true. Likewise in a city, this disaggregation can continue in both cases, by sectors, sub-sectors, individual businesses and households. Further, with water and UOW there is a need to consider both the LTS supply-side and smaller local-scale, demand-side, socio-technical options to manage that resource efficiently, with avoidance paramount. And by observing such systems consistently, through detailed disaggregation and a holistic view, with forecasts specifically taking into consideration multiple underlying factors, this provides the opportunity to unveil a plethora of demand- and supply-side socio-technical solutions at multiple scales. Such solutions result in both positive and negative cross-sectoral system impacts in both water and UOW, that need to be taken into consideration in planning exercises.

The fundamental concept of the derived benefits of a kilolitre of water saved or kilogram of UOW minimised along the resource value chain also holds true. These benefits come in terms of minimising the multiple resources used to produce that kilolitre of water or manage that kilogram of waste through subsequent collection, treatment and disposal. However, this is also where UOW exposes the nuance and challenges not always explicit in simplified overviews of IRP but often practiced by those applying it.

The first nuance is the non-homogeneous nature of the resource being observed. For water, the water quality cascade highlights that only a small proportion of the pristine potable water we treat for use in urban settings is actually consumed as drinking water. In homes, the vast majority is actually used for washing, toilets and gardens and thus requires lower quality water that can be derived from alternative sources (e.g. rainwater tanks and recycled water). This is also the case with UOW being of multiple qualities, with a spectrum of edible to inedible qualities dictating its reuse potential for human or animal consumption, or not at all. This is often dependent on timing or the putrescibility of the UOW material. Or from another perspective, the nutrient or energy generation potential. That is, AD provides an example of obtaining energy first and then nutrients from digestate in much the same way as recycled water within a household (e.g. shower or washing machine discharge used for garden watering). These varying quality requirements, cascading potential and temporal considerations unveil additional complexities for which IRP is well placed to analyse for both UOW and water IRP application.

Second, in water IRP, water is a resource 'input' to a property or house, whereas organics are a waste 'output' often generated from a food input of some form entering that property or garden organics growing on the property. In water, rainwater tanks are an example of an alternative input to the water system, while in UOW, a dehydrator deals with food waste output from a property but also an organic input to the downstream portion of the organic system that needs to be managed. This is where the nuance of working along the resource value chain of the system is required. As such, UOW might be more easily considered analogous to the water-wastewater value chain where the water entering a property needs to be efficiently used but then becomes a wastewater resource output that can then be collected, treated and reused or disposed in the same way as UOW. There are examples of this more fulsome 'water-wastewater' value chain in IRP, which specifically considers wastewater objectives. However, such studies still tend to focus on the up-stream portion of the water-wastewater value chain in terms of the water supply-demand gap or water efficiency opportunities to achieve a demand management target. This due to IRP's original intent to unveil efficiency and demand-side options as an alternative to LTS supply-side options such as dams. Further exploration of the more fulsome water-wastewater and food/organics-UOW IRP analogy poses a useful new perspective for IRP comparative analysis, which could assist in garnering deeper insights into both UOW and water IRP theory and ultimately practice.

Third, while in IRP demand- and supply-side options are considered equivalent (i.e. a kL saved is equivalent to a kL supplied) and thus $/kL used within supply curves to assess which sequence or portfolio of options might be more economic from a whole-of-society perspective, this is also more complex. Again, the complexity centres around the varying qualities of the resource, the quality cascade potential and temporal considerations (often simplified as merely net present value). These additional complexities make the case for the incorporation of MCDA-style features in IRP all the more important, including clearly identifying the key UOW management objectives (and criteria) such as the protection of human health and the environment but also additional objectives such as localised energy generation, GHG reduction or nutrient capture. Water management in urban areas is also complex with respect to having multiple objectives, if, for example, sustainability, resilience and liveability objects are included. Exploration of the incorporation of practical MCDA features within UOW IRP and consideration of trade-offs is a fruitful area for future research to help deal with the complexity of UOW and ways to make more informed decisions. Such complexity and fulsome use of MCDA currently appears to be absent in the emerging and fragmented Australian UOW management industry.

Finally, in terms of management, while waste is an essential service like water, it is managed differently in two key ways. Firstly, in Australia, water is typically owned and managed by state-owned corporations or councils and thus has a key planner/decision-maker to take the lead on a planning exercise or as a major stakeholder working together with state governments. However, this is not the case for waste in some of the metro cities in Australia, which have a highly fragmented and highly privatised asset ownership and management arrangement. Interestingly, in regional council areas, waste and water/wastewater are often owned and managed by the council, thus providing an opportunity to broaden the boundary of organics analysis and provide a fruitful area to expand UOW IRP cross-sectoral investigations and applications. That is, as a single entity, councils are able to more easily assess the costs, benefits and system cross-sectoral benefits available as well as potential negative impacts.

Secondly, water use is measured in accordance with user-pays pricing principles. However, in waste, in the vast majority of cases, measurement is not undertaken nor is volumetric or mass-related user-pays pricing applied. Hence, the highly fragmented, privatised and data-poor management of waste makes the application of IRP analysis and many demand-side management solutions challenging. However, even with fragmented and highly privatised asset ownership and management and lack of measurement and data, the use of the IRP process of inquiry can be applied. IRP has historically been highly beneficial in its ability to assist in the gradual identification and filling of knowledge and data gaps in the water industry. The use of IRP has the potential to benefit regional councils with more control over their assets and management, but also metro councils. It also has the potential to benefit individual building/precinct scale developments, which as identified in Section 4.2, are a significant and growing sub-sector that could assist in more localised UOW transformation.

9.2.2 SYDNEY-BASED NESTED CASE STUDIES

Sections 4.0 and 5.0 focused on the gaps identified in the literature and by waste management leaders in Sydney. These knowledge gaps mainly centring around the types and quantities of UOW and the potential innovative solutions available. While Section 4.0 provided an overview of Sydney and the characteristics affecting UOW, Section 5.0 provided a summary of the three nested case studies conducted at the mixed use/precinct, sub-LGA and LGA scales, which were used to fill identified knowledge gaps.

At the Sydney scale there is significant population growth and densification projected, especially in high rise MUDs and precinct scale developments, with over 50 precincts being developed/planned and 20% of projected dwellings needed by 2036 not yet built (40% by the middle of the century). This provides significant opportunity to transition to more sustainable UOW management practices. However, there is currently fragmented management in waste, discrepancies in system boundaries, ambiguity around definitions and a lack of data and measurement, especially C&I data. In addition there is a lack of a holistic picture on the multiple UOW streams, cross sectoral opportunities and collective knowledge on what interventions have already occurred that might affect UOW, projections and avoidance opportunities.

There is however significant longitudinal audit data on the residential sector across councils for SDs, MUDs and now also high rise MUDs, due to the growth in this sub-sector. The data showing the significant variation in organic waste generation between councils and between

SDs and MUDs but interestingly, the level of food waste in MUDs and high rise MUDs appears similar at around 2.5kg/week. The audits and more extensive research on the residential sector provide the opportunity for more disaggregated detailed residential sector forecasting and options analysis as advocated by IRP, although more transparency in data and cross sectoral sharing of data and analysis is required.

The case studies summarised in Section 5.0 aimed to fill knowledge gaps on multiple levels, with many breaking new ground.

Due to the growth in precinct scale developments in Sydney the CP case study was used to investigate the types and quantities of multiple streams of organics in one mixed use/precinct scale development. These including food waste, garden organics, used cooking oil, fats oils and grease from grease traps, wastewater biosolids and even pet waste. The used cooking oil and food waste from the retail food outlets actually measured, while other streams estimated from multiple data sets. The CP case study provided the first publicly available comprehensive assessment of various organics streams at the mixed use building/precinct scale in Sydney. Similarly it provided the first assessment of the potential feasibility of vacuum systems to transport food waste and AD to produce bioenergy along with high level estimates of costs and benefits. On-site AD feasible with respect to sizing and potentially producing as much as 20% of the electricity or 50% of hot water needs of the MUDs and offsetting AUD 85,000 of waste removal costs and similar avoided electricity/hot water costs as well as other benefits. Although, such benefits are highly dependent of the options considered, with vacuum being cost prohibitive unless incorporated at the design stage. Both on-site AD and vacuum systems used to transport food waste within buildings limited in application internationally.

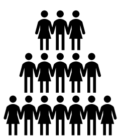
While the PUP case study provided the first publicly available assessment of multiple streams of organics and the generation of geospatial organics intensity hot spot maps at the sub-LGA scale, the IWC case study took the analysis much further due to the availability of multiple data sets including those from cross sectoral collaborators. Although there is a lack of C&I UOW data the IWC case study used a combination of data sets including NSW EPA Bin Trim audits to estimate the C&I food waste. It was found to be a large component and that approximately 11% of businesses are responsible for 50% of estimated food waste generation when assessed by ANZSIC code groupings such as accommodation, food services and manufacturing. This providing a useful focus for food waste avoidance, separation and treatment programs.

The IWC case study also went further than the PUP case study in terms of options development and assessment, the development of an extensive options inventory of over 50 examples and multiple sub-examples then used through an options workshop with IWC staff to develop potential illustrative options based on the geospatial hot spot maps identifying organics intensity. A suite of illustrative options subsequently assessed using whole of society costs and benefits, with options such as avoidance, composting at home and commercial on-site management having some of the lowest NPV costs and opportunities for GHG reduction. While FOGO, has one of the higher NPV costs. Again such costs and benefits highly dependent on the context in question.

9.2.3 NOVEL METHODS FOR FUTURE IRP PRACTICE

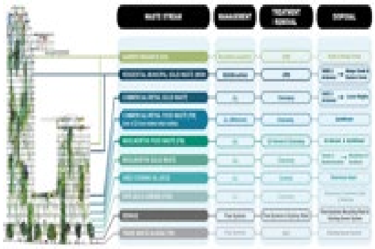
Through the Sydney-based nested case studies summarised in Section 5.0, I have identified and tested, to varying extents, novel methods not yet used in practice in the emerging Australian UOW sector. I have also sort to demonstrate that, for many of these methods there is a significant opportunity for future application. The aim being to help fill some of the UOW management planning gaps and opportunities identified within this thesis, and in some cases, highlight potential improvements for wider water IRP practice as well. Many of the methods stem from already strong IRP practice in the water industry but have the opportunity to be strengthened by using complementary systems thinking and sustainability transitions concepts and associated methods. The gaps and opportunities and specific methods identified in Table 9.1 are summarised below, along with potential limitations.

9.2.3.1 CONSIDERING THE DIVERSE STAKEHOLDERS



The need to improve the consideration of stakeholders and the social perspective in waste planning has long been advocated but is still lacking (Morrissey & Browne, 2004; Asefi et al., 2020). IRP identifies the need for the consideration of stakeholders in the early stage of a planning process (i.e. within IRP Step 1) and indeed the subsequent participation in the process. However, the complexity and fragmented management of UOW illustrates how this aspect of the process could be improved through a more structured approach. A more structured approach can help to think through the diverse stakeholders that need to be considered, and where appropriate, involved. Through the nested case studies, I identified how to consider UOW stakeholders using different forms of **stakeholder analysis**, a group of methods which are commonly used in soft systems/soft operations research/problem structuring (refer to Section 3.3.1 Box 4).

At both an individual building/precinct scale and larger LGA scale, **stakeholder analysis** in the form of **identification and mapping** was used in the CP and IWC case studies. This provided a clearer picture of the diverse web of stakeholders involved in UOW, which varies across contexts and scales. The **identification** was conducted by thinking through the UOW value chain, from generation of different streams by different sectors and sub-sectors in the urban environment, to disposal or end use of the materials generated. This was conducted both by



me individually as a researcher going through the process of collecting data and information for an individual building/precinct in the CP case study (see Figure 6.1) and through a facilitated brainstorming workshop with council representatives responsible for managing waste as part of the IWC case study. An important result of using the workshop format was to help the council representatives to think beyond the UOW they are used to managing (i.e. typically residential food waste and garden organics for metro councils) and obtain a far richer picture encapsulating the multiple stakeholders directly and indirectly involved in both generating and managing UOW in their LGA. This is particularly important for councils committing to targets to reduce UOW within their LGA.

Also, as shown in Figure 6.3, I conducted a more detailed **mapping** exercise with the IWC representatives during the stakeholder workshop. This involved consideration of the stakeholders control-influence-concern (Covey, 1989) in UOW management and subsequent categorisation (i.e. federal to local government, private organisation, industry body, community). The mapping exercise helped to illustrate the surprisingly diverse number of stakeholders involved in UOW management in just one LGA and the level of control required for individual stakeholders to take some form of action to help achieve targets and advance UOW management practices in that area. Such actions could include householders home composting or arranging private food waste pick-up by local entrepreneurs. They could also include council linking local cafes and community gardens with composting facilities and end product demand or with private waste contractors and their own premises to increase food and other UOW recycling.

Also, at a deeper level, through semi-structured interviews with a small diverse group of UOW management stakeholders as part of the PUP case study, **stakeholder motivations** were explored for those inclined to use innovative UOW management solutions. Such drivers and motivations covered a wide range of sustainability factors well beyond the narrow waste hierarchy often assumed to be a key impetus for individuals to take action at the time (see Figure 6.4).

When thinking about UOW, different forms of stakeholder analysis drawn from long-established soft system methods (refer to Section 3.3.1) help garner a broader and deeper understanding of the complex web of stakeholders involved in dense urban environments. They provide a much clearer picture for those undertaking a planning exercise of the multiple stakeholders that need to be considered and involved from planning through to implementation. Conducting such structured stakeholder analysis early in a planning process (i.e. within IRP Step 1) provides a means to identify potential key stakeholders to collaborate with to provide data and information, advice and knowledge and fulfil aspirational goals and objectives through pilots and implementation.

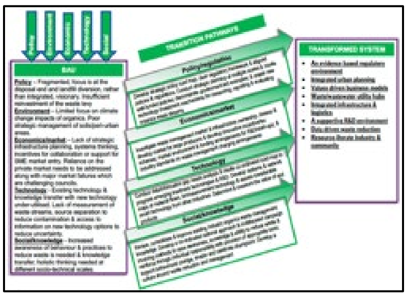
These methods have the potential to improve UOW management planning at the individual building/precinct scale, as illustrated in the CP case study as well as the LGA scale, such as in the IWC case study where a core planner/decision-maker can be identified. They can also be useful if considered by retail associations, retail management corporations with multiple sites, groups of councils, or at the city/regional scale where a key stakeholder with significant control of the system can take action towards more sustainable UOW management (i.e. 'a champion').

However, there may also be limitations. There may be no organisation to take a leading role in the planning exercise due to the scale of fragmentation of waste management or lack of knowledge of the system in question. Additional costs and time associated with these exercises might be involved, like expert facilitators to design and help ensure divergent systems thinking in workshops and capturing and mapping ideas or to obtain perspectives on motivations through multiple stakeholder interviews. However, these issues can be overcome if an organisation with significant control of the system takes up the lead planning role in a collaborative way. Or if the large array of participation and engagement tools available are utilised, such as workshops to help clarify motivations instead of semi-structured interviews, which help reduce costs and time where conflict or commercial in-confidence issues can be limited.

Stakeholder analysis methods are well established in systems thinking. The incorporation of these structured methods within IRP Step 1 would be highly beneficial for UOW to help better consider the growing diversity of stakeholders involved in UOW management in dense urban environments. These methods would also benefit broader IRP application to provide both a stronger theoretical underpinning to the stakeholder component of Step 1 but also improved structure to current practices.

9.2.3.2 CLARIFYING THE BROAD CONTEXT

Consideration of the broader context in resource planning is vital when developing effective solutions. While the broader context of an area is explored during the initial stages of an IRP exercise (IRP Step 1), for example, consideration of the physical topography of the area, current infrastructure, urban form, population growth and climate (i.e. an engineering or technical focus), such consideration of the broader context could be improved. This improvement achieved through more structured multifaceted investigations including a futures orientation, especially when planning often looks at 20-year, or more, time frames. Sustainability transitions can provide a useful additional lens and methods that can be incorporated into IRP practice by providing a futures orientation and specifically looking at other dimensions of the broader context around the drivers and pressures and barriers and opportunities.



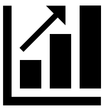
In the Organix 19 workshop, which I assisted in designing and facilitating for over 65 diverse waste management stakeholders, and conducted the analysis and synthesis for (Turner et al 2019), a **transitions model** (Jacobs et al 2016, 2017) was used. The model, based on sustainability transitions, was used to explore the Sydney UOW management context (see Figure 6.5). It provided a structured method to explore particular facets of the broader context such as the current BAU situation, key drivers, opportunities and challenges for change as well as the development of a vision of a circular economy future and potential pathways to get there. The workshop discussions were overlaid with a PESTLE model (as similarly advocated in integrated sustainable waste management practice) to help tease out policy, environmental, economic, market, technology, social and knowledge perspective

themes that emerged (see Table 6.2). Such a structured futures-orientated perspective of the broad context is essential for longer term planning exercises of resources during rapidly changing environments, as is currently being experienced in UOW. Several other useful key sustainability transitions concepts should also be considered up front, as described in Section 3.5, such as potential system shocks and trends, windows of opportunity, disruptive innovations on the horizon, and the risk of LTS lock-in and innovation and adaptive management lock-out.

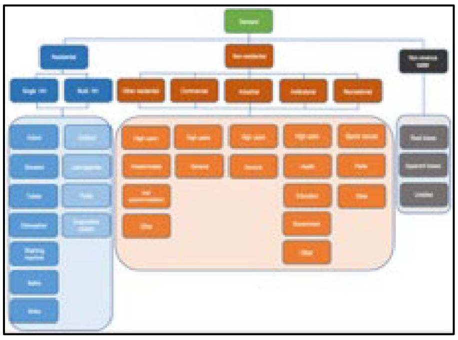
Limitations of this kind of workshop include the risk of underrepresentation of the diverse stakeholders involved along the value chain, over representation of specific groups or particular ‘voices’, costs, lack of visioning, poor workshop design, facilitation, capturing and analysis of the data, and a lack of a tangible ‘outcome’ from the process. However, all of these can be pre-empted or overcome through best practice workshop design and facilitation including using stakeholder analysis to think through the participants required and directly tying the process to policy or planning strategy development. By tying to a policy or planning exercise this ensures the participants feel their time is valued and well spent and the rich knowledge gained is effectively taken into consideration and utilised.

The use of such a structured sustainability transitions model using diverse stakeholders in a workshop environment provides a significant opportunity to advance UOW planning. As does consideration of key sustainability transitions concepts in a structured way to help establish a broader picture of the context at the commencement of an IRP planning exercise. The use of a transition model and consideration of broad sustainability transitions concepts could also be highly useful in broader IRP application and warrant further exploration into how they can be incorporated within IRP practice in a structured way.

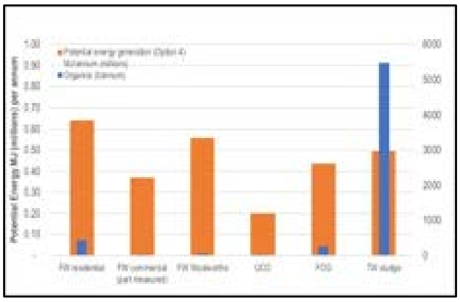
9.2.3.3 CONDUCTING RESOURCE DISAGGREGATION INVESTIGATIONS AND FORECASTING

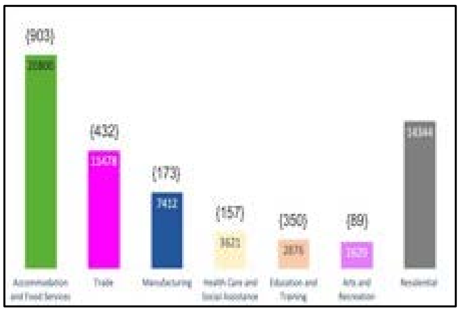


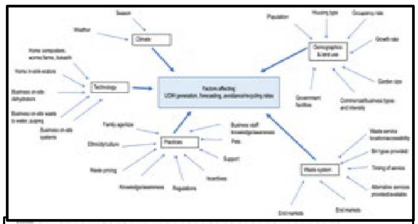
While the waste management gaps and opportunities identified in Section 2.5 do not specifically highlight the need for resource disaggregation or forecasting, they do identify the need to garner a broader and deeper socio-technical systems perspective and sufficient contextual detail to help inform decisions, even with data gaps. A key strength of IRP, similar to systems thinking, is the disaggregation of the system being observed into its component socio-technical parts (i.e. sectors, sub-sectors, micro components/end-uses) while simultaneously considering the holistic picture (see Figure 7.1). This combined bottom-up and top-down analysis is part of garnering the contextual detail within IRP Step 2, necessary to effectively manage a resource and design a mix of appropriate management solutions for that specific context. Another strength, due to several decades of practice, is to pool data and information together from disparate sources to achieve such a holistic yet detailed picture and gradually and systematically improve data for modelling and analytical purposes.

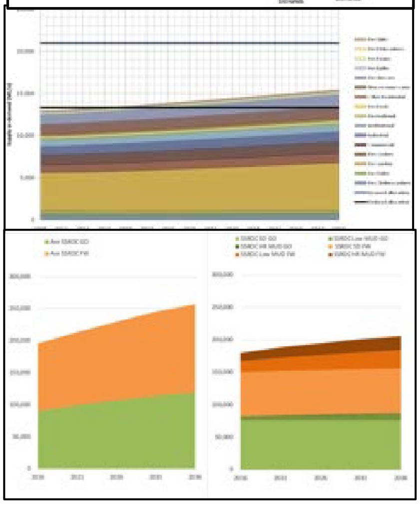


Due to the acknowledged paucity and fragmented nature of UOW data, all three case studies of varying scales were used to assess what data was available and how to **pool disparate data sets** of varying quality and a variety of sources together, from measured to estimated and from literature to first principles. Key sources were identified through stakeholder analysis and in all cases brought together disparate stakeholders and datasets never combined before in the Australian context. Despite data availability and privacy and quality challenges, this advanced both the holistic and detailed picture of UOW at various scales in Sydney for the first time, and due to the types of materials combined provided new **snapshot insights**. For example, the feasibility of localised building/precinct scale UOW collection and AD energy generation, as in the CP case study and at the LGA scale likely non-residential sub-sectors responsible for high volumes of UOW that could be targeted for further data gathering and options development within the IWC (see Figure 7.5 and Figure 7.6).







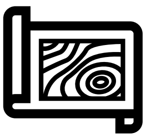


Another method drawn from water IRP practice, based on disaggregation, is the careful consideration of the **factors** driving resource generation or use (see Figure 7.9). Such factor analysis assists in more detailed sector, sub-sector and end-use/micro-component **forecasting** (see Figure 7.10) and the opportunity to see more clearly the waste contribution from each stream and each of the sectors and sub-sectors. A simplistic versus more detailed forecast of residential food and garden organics was conducted for the SSROC area in Sydney, representing over a third of Sydney's population, to illustrate how forecasts can be significantly affected by these factors (see Figure 7.10). As seen in other industry sectors, without such disaggregated and factor-based forecasting, projections are likely to over forecast the supply-demand gaps and services needed and result in over capitalisation of LTS potentially not used for years.

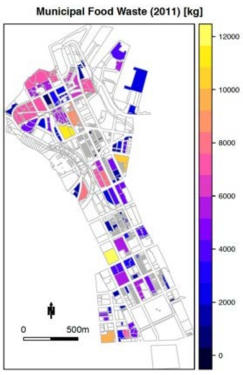
Holistic combined with detailed disaggregated sector, sub-sector and end-use/micro-component UOW analysis is not being conducted in Australia despite the significant improvements this could make in UOW management planning and decision-making for different streams and qualities of UOW. Such detailed examination of the waste generated can provide the opportunity to develop options that respond to the specific context being observed and ways to both minimise the waste produced and subsequently make the most of the resources generated (e.g. chemical extraction, bio energy potential, nutrients). Neither are the various factors likely to affect future forecasts being considered in detail, which could have significant impacts on the amount of UOW actually produced in the coming years. The major limitations being that the different streams are not considered holistically together in one planning or modelling environment due to the fragmented management of organics and the lack of measured data available for analysis and modelling. However, as identified in Section 7.1 lack of data was an issue in the water industry. This has been overcome over many years through the gradual roll-out of universal metering, focused filling of identified gaps and gradual development of end-use studies and models drawing together disparate datasets. This is feasible for UOW but requires targeted research. It requires a focus on sub-sector and end-use/micro-component analysis and forecasting (similar to that conducted in the water and energy sectors) including deeper understanding of the factors likely to affect future trends in those sub-sectors and end-uses/micro-components.

Both the IRP process of enquiry and focused research, together with the implementation of regulations around measurement and data collection as seen in other countries, could significantly assist in improving UOW management in Australia. The pooling of disparate datasets conducted for the case studies highlight the key types of stakeholders that need to work together to improve such datasets and accessibility, privacy and quality issues. This could be used as a stepping-stone to fill knowledge gaps while advances in measurement are progressed, especially in the non-residential sector. Such pooling of data and stakeholder efforts would benefit from shared data platforms and data mining and leveraging of existing data not currently systematically collated or analysed. Having such stakeholders working together could significantly advance UOW management but requires appropriate government leadership from federal and state to local government as well as regulatory requirements to do so (i.e. a carrot and stick approach). With, as identified in transition management (Section 3.4.3), government playing key roles from law enforcer to mediator.

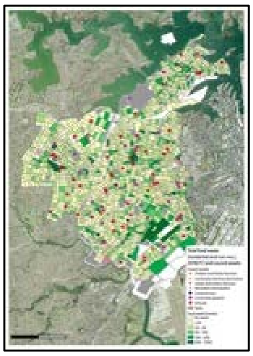
9.2.3.4 MAPPING & VISUALISING THE RESOURCE SYSTEMS



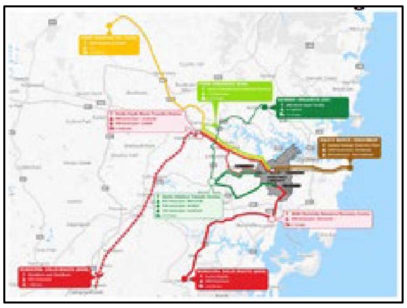
Granular geospatial mapping and visualisation is not typically conducted as part of water IRP; nor is it used in UOW management planning. However, a recent review of waste management planning approaches (Asefi et al., 2020) identified the use of GIS mapping and visualisation as an opportunity to help stakeholders better understand and engage in complex systems. From a soft-systems thinking perspective, this is analogous to the use of a form of 'device' in stakeholder engagement (Section 3.3.1). Due to the complexity of UOW, in terms of different streams from different sectors and sub-sectors with different characteristics (i.e. perishability, nutrient quality, bioenergy potential), mapping and visualisation of the different streams was seen as an opportunity. This is in terms of moving away from the typical narrow view of only focusing on residential food waste and garden organics that are managed by metro councils, towards other broader UOW management. Other UOW examples include used cooking oils, non-residential food waste, fats, oils and grease from grease traps and wastewater biosolids. The use of mapping and visualisation provided an opportunity to assist in both elucidation of the disparate streams and systems as well as facilitating subsequent engagement with stakeholders on potential solutions as discussed in Section 8.1.1.2.



All three case studies used geospatial mapping and visualisation. Each advanced particular aspects of mapping and visualisation concepts and methods. Initially in the PUP case study, and subsequent IWC case study, individual UOW geospatial **intensity hotspot maps** (see Figure 7.13) were created for the first time at the sub-LGA/LGA scales for each of the streams of organics for individual sectors where data was available. These individual maps were also combined to provide overall intensity hotspot maps to illustrate significant organics generation sources. The ability to visualise both combined and single streams and sectors helped when thinking through different management opportunities at different scales and even different characteristics, such as perishability, nutrient density and bioenergy potential.



Another form of mapping and visualisation developed in the IWC case study was **asset overlay** (see Figure 7.14), in which a number of council and government assets were plotted in conjunction with various UOW generation hotspot maps. This provided an indication of the potential UOW generation of those government premises as well as potential UOW collection hubs for the local community. The asset overlay maps were used with council staff in a workshop environment (as discussed in Section 8.1.1.2) to help think through UOW option opportunities related to their specific assets. The intensity hotspot maps enabling engagement with the various UOW streams in combination with assets, for the first time.

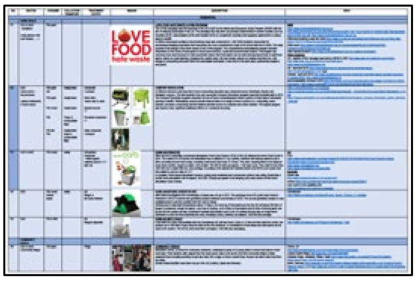


Finally, for the CP and IWC case studies, **route maps** were generated (see Figure 7.15), illustrating the surprising distances materials generated from a particular building/precinct or LGA travel for treatment and disposal or use. Both the route mapping as well as intensity hotspot and asset overlay mapping and visualisation helped to identify the opportunity for more localised collection, treatment and use to minimise transport across the city and local resources utilisation, such as nutrients and bioenergy. All the maps used in external industry workshops and conference environments stimulated significant discussion due to their novelty and ability to engage stakeholders (Jazbec et al., 2021).

Geospatial mapping and visualisation provide significant opportunities to improve future UOW management planning and decision-making, from building/precinct to city, and even regional scales. Although there is a lack of available data for some streams, current research is aiming to overcome this for Sydney through the development of new data collation and analysis methods built on the case studies within this research (Jazbec et al., 2023). The various geospatial mapping and visualisation methods also have potential in broader IRP application, for example, helping to visualise high-water users that might benefit from targeted demand management programs in areas with constrained assets, or 'local IRP'. This is especially relevant with the new era in smart metering providing more granular temporal usage data. However, in both UOW and water IRP potential applications, the geospatial granularity needs to be considered carefully to ensure data privacy agreements are not contravened. Also, in UOW, combining individual maps to create hotspot maps will need careful consideration of the metrics used due to the varying characteristics of the materials. Despite these potential challenges, the various forms of mapping and visualisation provide a highly beneficial area of research for both UOW and water IRP to assist in better conceptualising, analysing and engaging with complex systems of various scales and aid in more informed planning, analysis and decision-making.

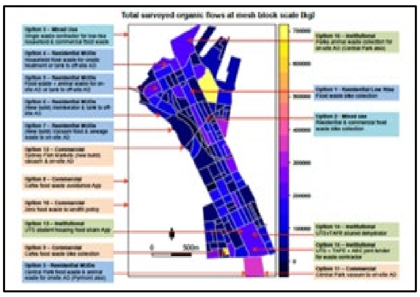
9.2.3.5 IDENTIFYING AND DEVELOPING OPTIONS

As identified in the waste management planning gaps and opportunities, there is a need to consider a broader network of complementary options responsive to the drivers, pressures and specific context of an area being examined. Such consideration of options also needing to preserve resources and avoid LTS lock-in and innovation and adaptive management lock-out. IRP has a long-established practical focus on options identification and development (IRP Step 3). Due to its disaggregated and context-focused thinking approach, it has assisted in the paradigm shift and implementation of a vast array of demand-side options in the water industry. These options respond to the disaggregated sectors, sub-sectors and end-uses/micro components in each context (IRP Step 2) even with data paucity. Such demand-side options are considered equal to supply-side options and led to significant funding in demand-side solutions in the Australian water industry. Such funding is not yet seen in the UOW management sector, despite avoidance being identified as a priority for many years. With the current window of opportunity in the emerging UOW management sector, there is an opportunity for demand-side UOW solutions to flourish. This in a similar way to the water industry during the Millennium Drought, where IRP was used as a key framework to aid in options identification and development.



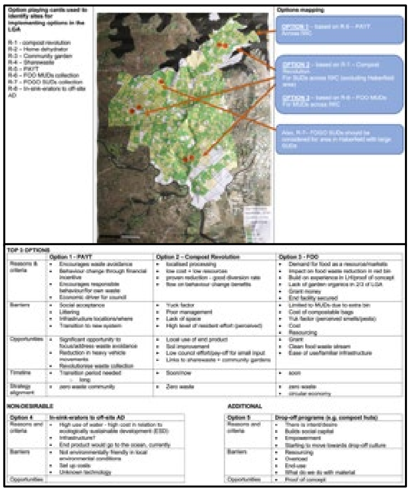
To open up the options available and to fill the gap in identifying and developing UOW solutions in a structured way, IRP disaggregated divergent thinking was used. Initially through the PUP case study and then the subsequent IWC case study, I developed an **options inventory** of a wide range of potential UOW management solutions (see Appendix E). The inventory highlighted the vast array of socio-technical solutions available and being implemented at different scales, for different sectors, and for different UOW streams. The inventory was developed from two separate international scans of the grey literature looking outside the existing practices in Australia in 2017 and 2019. It showed the significant variety of socio-technical solutions not yet embraced in the emerging Australian UOW management industry sector. It also showed the rapid rise in innovation in just two years, which is still ongoing. As discussed in Section 8.1.1.1, the inventory used a structured disaggregated approach to investigating such options (i.e. sectors, sub-sectors, end-uses/micro components, UOW streams, scales, timing and points along the value chain). This structured and outward-looking international scan was essential in options identification in emerging sectors to help minimise the risk of repeated LTS lock-in and adaptive management and innovation lock-out. Another important aspect of the scan was the use of real international examples where the options have been implemented or are being trialled to provide some form of evidence in the fledgling, and somewhat risk averse and LTS focused, waste management sector in Australia.

Based on the options inventory, an **options development** exercise was also conducted for both the PUP and IWC case studies. In both cases, the GIS mapping and visualisation hotspots maps (refer to 7.3.1.1) were used to assist in the options development and associated **options mapping** with two different methods adopted. In the PUP case study, I conducted the options development and mapping alone based on my personal knowledge of the area being investigated, the scan of potential international options collated and the hotspot maps created



based on the limited data available. Figure 8.1 shows the output of the exercise, which was used as an illustration of the types and scales of options that could be considered for the particular sub-LGA being examined, the densest in Australia at the time. The output was used as a 'device' in a subsequent workshop to engage a diverse group of stakeholders with interest in advancing UOW management innovation in the area, similar to an 'arena' in transition management. The workshop expanded the knowledge of potential options available for stakeholders and potential benefits of more localised collection and treatment. It also assisted in generating interest in innovative research, that is, building/precinct scale AD (i.e. the CP case study) not previously considered in Australia in such a dense urban environment.

The second method used to develop and map options took a more collaborative approach. I developed and co-facilitated an **options workshop** with 15 IWC staff involved in waste management. After an introduction to the IWC case study, hotspot maps were provided to the participants to focus on different sectors (residential, non-residential and council assets) on



different discussion tables. The participants were provided with the options inventory before the workshop and asked a series of questions during the workshop to help them identify and locate desirable options on the maps and discuss why they were chosen, and the potential barriers and opportunities (see Figure 8.3). They were also asked to identify non-desirable options and any additional options not yet identified in the inventory. Helping to expand knowledge of possible context appropriate options was an important aspect of this exercise, but this time I was tapping into the participants' extensive expertise and knowledge of the area to assist in 'context focused thinking'.

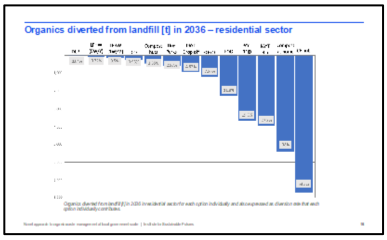
A limitation to the development of an options inventory might be the time required to develop it and gain access to up-to-date information on the outcomes of trials and implementation. Often, trials or new innovative approaches are highly advertised at the start, yet the outcomes and failures are rarely publicised. Collated examples of food waste and organics management are available but often fairly limited in scope. Hence, the need for government leadership in developing an up-to-date accessible repository of international and local examples of innovative UOW management for practitioners during this window of opportunity. This would help minimise duplication of research and investigations, as experienced in the water industry during the Millennium Drought crisis. Also, as in strategic niche management, there is a need for piloting and the set-up of demonstration sites of innovative socio-technical approaches to test, learn and share knowledge in the Australian context.

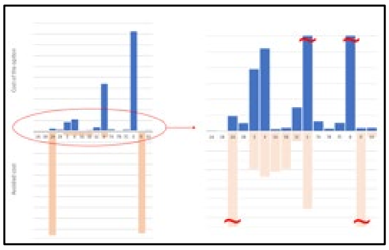
With respect to options development, examples of organic options considered in the past have often been limited in scope and streams and only a small component of the overall waste options considered. With the shift in policy focusing specifically on organics, more options need to be put on the table using divergent thinking such as IRP and systems thinking. While many councils may rely on consultants to develop options, the IWC case study workshop illustrates the benefits of tapping into councils own local knowledge as part of the process. IWC feedback on the IWC workshop process was overwhelmingly positive, including discussion on how useful the maps were as tools for engagement and how important it is to bring internal stakeholders together to generate ideas and inspire each other. Expansion of the method to broader stakeholders and the community would broaden knowledge and perspectives, identify potential barriers and opportunities, and obtain better public engagement, buy-in and ownership of the solutions implemented.

Both the options inventory and options development and mapping methods provide significant potential improvement in UOW management planning. However, again, due to lack of data, the mapping component may prove more difficult in some circumstances. Notwithstanding, divergent expansion of the UOW options possible, using evidenced-based examples together with context-focused thinking (made possible by IRP Step 2 disaggregation), provides an opportunity to break LTS thinking and embrace innovation in UOW in a structured way. This is especially the case when using a workshop environment and drawing on participants' expertise. Both the options inventory and approach to options development and mapping also provide opportunities in water IRP (i.e. local IRP) not yet explored to their full potential.

9.2.3.6 COSTING AND ASSESSING OPTIONS

As identified in Section 2.5, there are various methods used to assess options. However, many of these have a bias (i.e. economic or financial in the case of CBA or environmental in the case of the waste hierarchy and LCA), or in the case of food waste, do not adequately address the multiple perspectives of stakeholders involved (Mourad, 2016). Planning exercises incorporating MCDA features are seen as a way to help address these issues and more adequately deal with the complexity of multiple objectives in complex systems. IRP Step 3 considers demand- and supply-side options on an equivalent basis using consistent boundaries and assumptions with many water IRP water examples demonstrating the assessment of multiple cross-sectoral objectives and potential monetisable and non-monetisable costs and benefits (i.e. resource use reduction, GHG reduction, preservation of unique environmental habitat) in line with MCDA. However, the complexity of UOW management pushes the assessment of options in relation to objectives and associated criteria to a more complex level than perhaps currently practiced in IRP. Hence, as discussed in Section 8.2, IRP could benefit from incorporation of more MCDA features as well as additional aspects of third- and fourth-wave systems thinking, especially those relating to the consideration of power dynamics.



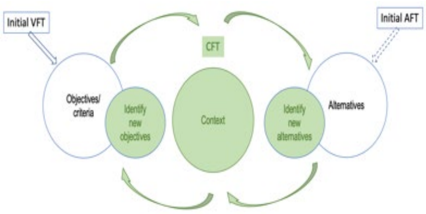


The IWC case study was initially intended to be used to assess options based on IRP practice and test MCDA approaches. However, due to various circumstances, such as major restructuring of the council executive team and decisions on which organics options should be progressed made above the waste management team, this did not eventuate. Hence, only illustrative options and partial aspects of costing and assessment were conducted. This included, with the data available, assessment of potential **avoidance** and/or diversion from landfill of a spectrum of potential options of various scales (see Figure 8.9). It also included assessments of the **costs and benefits** of the selection of illustrative options for the IWC (see Figure 8.10) and other stakeholders in the form of whole-of-society costs and benefits. The options analysis indicated options such as avoidance and composting in the home had relatively low unit costs and provided significant whole-of-society benefits. In comparison FOGO had one of the highest unit costs and represents an LTS replacing an existing LTS with little additional benefit. Options savings, costs, benefits and who-pays tables and graphs (including supply curves) are commonly used in IRP analysis and assessment to help decision-makers better understand various aspects of the options available. Having the costs and benefits transparently considered from a whole-of-society perspective (i.e. beyond merely financial) enables who-pays and cost and benefits sharing to be discussed among key stakeholders.

When a full analysis is undertaken, the options are normally prioritised according to objectives and criteria, initially articulated as part of IRP Step 1, but revisited as part of IRP Step 3. The extent of benefits considered are dependent on the data available and the core identified objectives of the planning exercise in question. MCDA-style analysis, and where possible, participatory workshops are used to aid in the prioritisation of objectives and criteria and associated responding portfolios of options (i.e. not a single silver bullet option). Although the extent of the participatory process and MCDA analysis vary significantly in practice (and as identified in Section 3.3.2 Box 5), even the best examples of decision-making processes are sometimes overridden by the power of politics.

An MCDA was not possible in the IWC case study. However, consideration of **objectives and criteria** needed to make decisions about options were explored within the options development workshop with IWC participants. During the workshop development and process it became evident that specific UOW objectives and criteria were not being considered for pilots nor for implemented programs being considered by the council but rather ad hoc approaches. Hence, as part of the options development workshop, the kinds of questions that might need to be asked when deciding on options were discussed. These were synthesised into a PESTLE framework to help categorise the different perspectives identified, as shown in Table 8.3. These 'criteria' helped to illustrate the multiple dimensions of decision-making actually occurring in practice and needing to be considered in a typical metro council yet with the lack of structure to help think through prioritisation of the option/s taken to pilots and/or full scale implementation (IRP Step 4). This potentially results in costs and/or councillor's decisions overriding the decision-making process (i.e. dominant power as identified in third-wave systems thinking).

While advanced assessment methods have been used in IRP, and there may be highly developed options assessment methods in MCDA theory, these need to be translated into practice for UOW planning and involve multiple stakeholders. They also, importantly, need to involve iteration between identification of objectives, the context and potential options (i.e. value-context-alternatives focused thinking), as illustrated in Figure 8.7, if a network of complementary options responsive to the drivers, pressures and specific context are to be developed as advocated in the literature. The assessment of UOW options and effective practical decision-making is an area of important research needed at this point in time. This especially the case in Sydney, where many councils are grappling with how to respond to new policy direction and deciding between options, often with long-term contract implications, but with deficient methods to do so.



9.3 OPTION INVENTORY

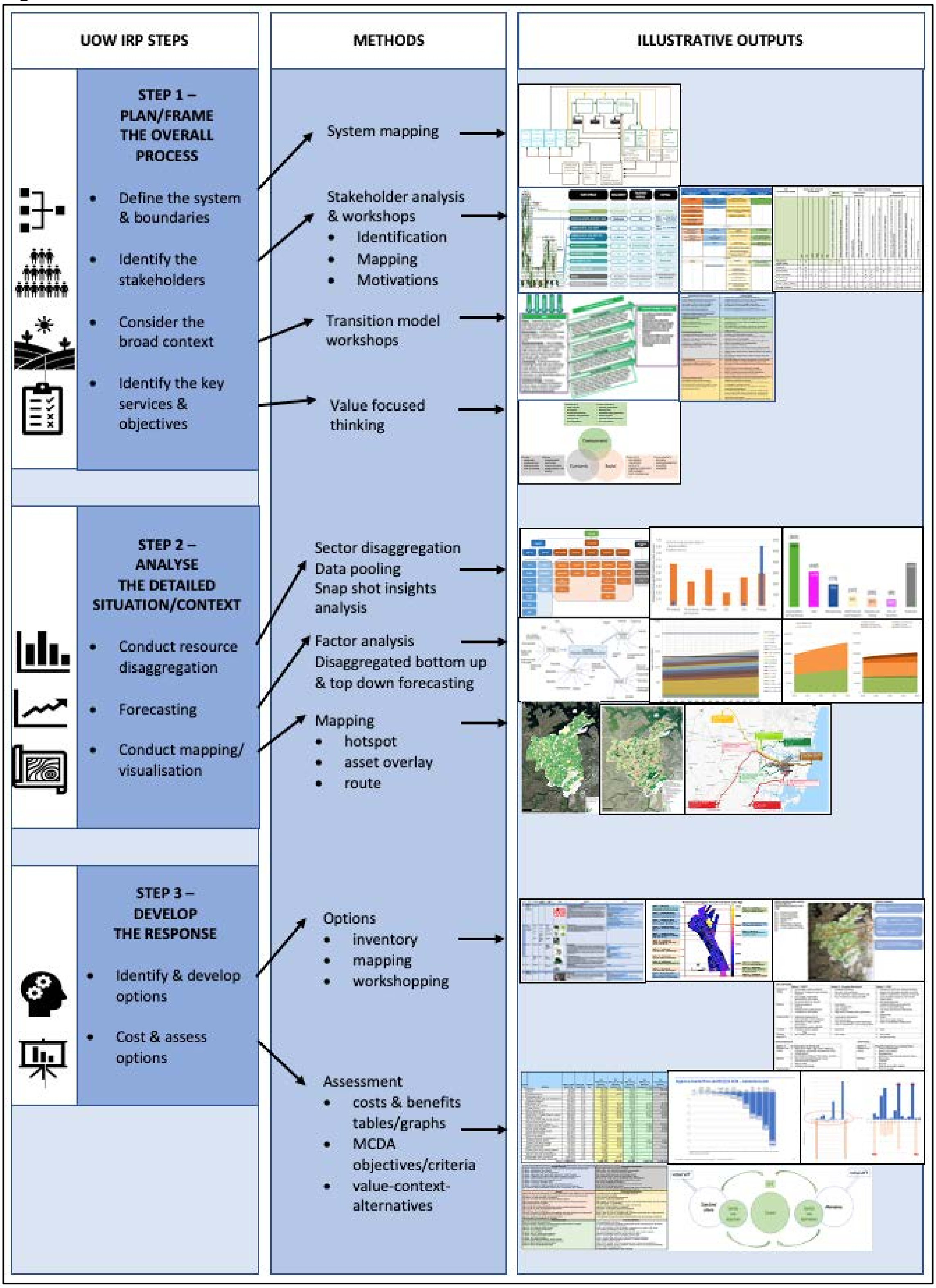
As identified in Section 9.2.3.5, initially through the PUP case study and then the subsequent IWC case study, I developed an options inventory. The inventory contains a wide range of potential socio-technical UOW management solutions available and being implemented at different scales, for different sectors, and for different UOW streams. The inventory is based on a structured disaggregated approach to investigating such options (i.e. sectors, sub-sectors, end-uses/micro components, UOW streams, scales, timing and points along the value chain). The inventory included in Appendix E provides the basis of a useful resource for those practitioners wanting to explore a wide range of potential UOW solutions for their particular context.

9.4 ELEMENTS OF A POTENTIAL UOW MANAGEMENT IRP FRAMEWORK

While it was not possible to implement a full UOW IRP process with the three opportunistic nested case studies they do illustrate how various IRP concepts and methods supported by systems thinking and sustainability transitions could be useful in advancing UOW planning, analysis and decision-making.

Figure 9.1 provides an outline of an UOW IRP framework, concentrating on the first three steps, highlighting the methods discussed that could be used in UOW and the kinds of outputs generated that could assist in and advance planning, analysis and decision-making.

Figure 9.1 – Outline of an UOW IRP framework



9.5 CONCLUSIONS & NEXT STEPS

Food together with other broader organic waste generated in urban environments is causing major issues globally and in NSW. This thesis has identified many of the key issues as well as policies and socio-technical solutions aiming to address them. It has highlighted the growing complexity of UOW management and the need to consider positive and negative cross-sectoral impacts, including the potential for energy generation from organics and the challenges from liquid organics on wastewater. The thesis has also made the case for transitioning the emerging UOW industry to more sustainable practices through improved planning, analysis, and decision-making.

The thesis has surveyed an array of planning and decision-making approaches already used in waste management. It has also delineated the acknowledged gaps and opportunities documented within the literature and identified others from considering current practice. These gaps and opportunities range from a lack of a systems view and appreciation of the detailed context of a jurisdiction to the need to embrace a mix of options and more effectively engage stakeholders in the planning and decision-making processes. Looking at the key gaps and opportunities identified, this thesis has argued that IRP, as used in both the water and energy sectors for decades, can have a role to play. Further, with augmentation from systems thinking and sustainability transitions concepts and methods, IRP can fill additional identified gaps and capture opportunities while improving IRP not only for UOW application but potentially also for aspects of water planning as well, as identified in Table 9.1.

Although it was not possible to apply the full spectrum of IRP concepts and methods to UOW nor within this thesis, various IRP, systems thinking and sustainability transitions concepts and methods were applied to a selection of Sydney-based nested case studies. A number of these applications have been for the first time. The aim was to fill industry identified knowledge gaps in both quantifying UOW streams and socio-technical UOW management solutions relevant to the Sydney context. The application of such concepts and methods enabled the development of the foundations of an UOW IRP framework similar to that used in the water industry but explicitly augmented with systems thinking and sustainability transitions methods, as illustrated in Table 9.1 and Figure 9.1.

While this thesis has added to the body of knowledge about UOW in Sydney that can be used more broadly and has broken new ground by demonstrating the benefits and potential of IRP for application in UOW management, it has also highlighted a number of remaining gaps and various limitations. These gaps and limitations will need further actions to overcome and provide opportunities for both policy makers and for further research as summarised as follows.

On a policy front, based on the Sydney-based case studies, there is an obvious need for key stakeholders to work together to improve UOW data for better planning, analysis and decision-making, including, for example:

- Moving towards regulatory requirements for the measurement and reporting of waste generated along the value chain and associated application of user-pays pricing principles similar to those in water and energy essential services in Australia and organic waste management in other international jurisdictions.
- Annual registration and central recording of on-site organic collection and treatment to assist in garnering a better appreciation of the level of on-site treatment in place, its efficacy and the potential for expansion to help achieve multiple policy objectives.
- Sharing of the limited currently available fragmented data, taking into consideration privacy and commercial concerns, to help triangulate and improve analysis in the short term and as new data becomes available.
- Collation and sharing of that data and analysis (i.e. a centralised industry repository/portal) to improve industry knowledge and management.
- Collation and sharing of innovative UOW management examples and demonstration sites, along with their lessons learnt, again on a centralised industry repository/portal, to help break barriers to trialling and implementation of innovative solutions (i.e. such as opportunities for smaller local-scale AD).

In each case, government, especially state government, has a responsibility to take a leading role from regulation of measurement and reporting to facilitation of knowledge sharing.

For researchers working closely with industry, there is an opportunity to develop the UOW IRP framework and specific methods further from stakeholder analysis and the use of a transition model to mapping and visualisation and the development of options inventories. There is particular scope to develop methods in the sub-steps not covered in as much depth within this thesis, such as:

- costs and benefits analysis of options for input to the generation of costs and benefits tables and supply curves to aid options development and comparison

- MCDA processes and criteria development specifically for UOW management and use within an UOW IRP framework
- an iterative process of value-context-alternatives focused thinking to help create context specific solutions of varying scales and move away from the silver bullet solutions of LTS
- finding ways of dealing with power dynamics, as considered in third-wave systems thinking, which is a particular issue in the waste industry due to such reliance on the private sector and overall fragmented management.

Such development would benefit from collaborative transdisciplinary industry-based research.

With further development of methods (i.e. mainly within IRP Step 3), the UOW IRP framework could be tested, especially in:

- regional councils/LGAs with control over their waste and wastewater services, as a leading organisation to help uncover data around cross-sectoral costs and benefits
- metro councils and groups of councils (i.e. regional organisations of councils) with clear boundaries and policies and directions for waste management
- the city level (i.e. Sydney) to encourage broad stakeholder engagement and garner a more holistic picture of the organics in the city (which is still illusive) and the array of possible solutions available at this critical juncture
- precincts and large MUD developments due to their increased dominance in dense urban environments and opportunities for more local-scale treatment, reduced costs and increased benefits, thereby aiding the circular economy as well as the concept and practice of 'local IRP'.

This development requires multiple stakeholders with councils playing a key role.

For both policy makers and researchers, there is also an opportunity to further investigate the nuances of and differences between UOW and water IRP for more in-depth appreciation of potential application, such as consideration of:

- the varying quality, temporal limitations and cascading potential of the resources being observed to help better reflect possible variation in the service unit/s being assessed (i.e. linked to MCDA)
- working along the IRP water-wastewater and food/organics-UOW value chain analogy to improve insight into the comparison and practical application of IRP

- demand- and supply-side options equivalence and the development of practical MCDA approaches to help stakeholders consider the service, objectives and criteria for practical comparison of UOW options and portfolios of options and informed trade-offs
- the current data availability and needs for effective UOW IRP and development of a data framework to assist current IRP application while moving towards better measurement, reporting and analysis.

Such development is an opportunity for industry-based research.

Despite its potential limitations and the suggested additional actions and research, IRP shows real promise in the emerging UOW sector, even with such fragmentation and data paucity. This especially the case during the current window of opportunity in Australia over the next 5 to 10 years. With the addition of systems thinking and sustainability concepts and methods, IRP has the potential to break the perpetual waste management LTS focus, with the associated risk of LTS lock-in and adaptive management and innovation lock-out. This is in a structured and collaborative way, as seen in the Australian water industry during the Millennium Drought, and like water, providing the opportunity for avoidance and innovation to flourish with all the associated cross-sectoral benefits.

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APPENDICES

APPENDIX A – PYRMONT-ULTIMO PRECINCT SCALE ORGANICS MANAGEMENT SCOPING STUDY

Turner, A., Fam, D., Madden, B and Liu, A. (2017). *Pyrmont-Ultimo Precinct (PUP) Scale Organics Management Scoping Study*. Prepared for Sydney Water Corporation and the NSW Environment Protection Authority by the Institute for Sustainable Futures, University of Technology Sydney

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APPENDIX B – CENTRAL PARK PRECINCT ORGANICS MANAGEMENT FEASIBILITY STUDY

Turner, A., Fam, D., McLean, L., Zaporoshenko, M., Halliday, D., Buman, M., Lupis, M., & Kalkanas, A. (2018). *Central Park Precinct Organics Management Feasibility Study.* Prepared for the City of Sydney and Flow Systems by the Institute for Sustainable Futures, University of Technology Sydney

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APPENDIX C – ORGANIX19: ORGANICS WASTE MANAGEMENT IN A CIRCULAR ECONOMY

Turner, A., Fam, D., Jacobs, B., & Jazbec, M. (2019). *Organix19: Organics Waste Management in a Circular Economy*. Institute for Sustainable Futures

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APPENDIX D – ORGANICS REVOLUTION: PLANNING FOR 2036 AND BEYOND

Jazbec, M., Turner, A., Madden, B., & Fam, D. (2020a). *Organics Revolution: Planning for 2036 and beyond*. Prepared for Inner West Council, Institute for Sustainable Futures, University of Technology Sydney.

This Appendix is confidential.

APPENDIX E – OPTIONS INVENTORY

Options inventory (Turner, 2020) in Jazbec et al. (2020a) *Organics Revolution: Planning for 2036 and beyond*. Prepared for Inner West Council by the Institute for Sustainable Futures, University of Technology Sydney.

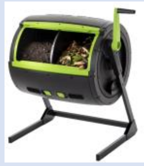
Inner West Council

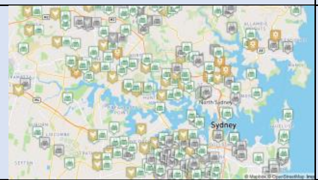
Organics Evolution: Planning for 2036 & beyond

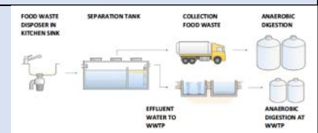
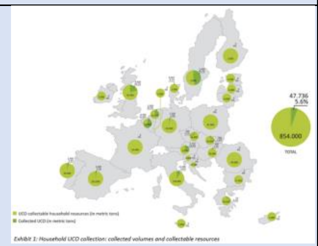
Options Inventory

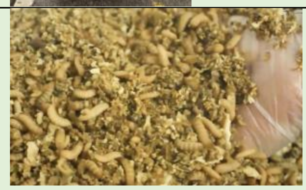
Prepared by:
Turner, A
February 2020

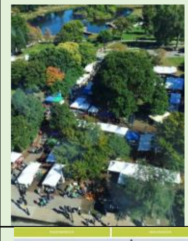
IWC OPTIONS INVENTORY

NO.	SECTOR	STREAMS	COLLECTION TRANSPORT	TREATMENT/ OUTPUT	IMAGES	DESCRIPTION	REFS
						RESIDENTIAL	
	HOME SCALE						
R1	SUD & MUD - avoidance (meal planner, left over recipes……)	FW (part)				**LOVE FOOD HATE WASTE (LFHW) PROGRAM** The LFHW campaign was first launched in the UK in 2007 by the Waste and Resources Action Program (WRAP) with the aim of reducing food waste in the UK. The campaign has now been successfully implemented in several countries such as Australia (2010), New Zealand (2016) and Canada (2018) to complement voluntary and regulatory agreements to reduce waste to landfill. In 2009 a food waste avoidance benchmarking study was conducted by 1,200 NSW residents responsible for purchasing/managing food within their household, the most comprehensive study of its kind at that time in NSW. The study assisted in the design of the NSW version of the LFHW program. The comprehensive and adapting program provides information on the levels of food waste in homes and economic, social and environmental impacts. The program has numerous tools and resources to help households reduce their food waste such as web and app based tools to audit food waste, videos on meal planning, shopping lists, portion sizes, left over recipes, advice on keeping food fresh etc. and linkage to composting and worm farms for unavoidable food waste. It also links to the work place, partnership programs and grants.	**NSW** https://www.lovefoodhatewaste.nsw.gov.au http://www.environment.gov.au/system/files/resources/0a517ed7-74cb-418b-9319-7624491e4921/files/factsheet-waste-profile-nsw.pdf, https://www.lovefoodhatewaste.nsw.gov.au 2009 benchmarking study fact sheet https://www.eccnsw.org.au/getattachment/What-we-do/Love-food,-hate-waste/120437LFHWBenchmarkStudyColour.pdf.aspx 2009 report https://www.lovefoodhatewaste.nsw.gov.au/sites/default/files/2018-06/Report%20-%20Benchmark%20Survey%202009.pdf other reports/research https://www.lovefoodhatewaste.nsw.gov.au/about-us/research **Other locations** UK - original LFHW campaign launched by WRAP in 2007 http://www.wrap.org.uk/about-us/our-history, http://www.wrap.org.uk/content/love-food-hate-waste https://www.lovefoodhatewaste.com NZ - launched 2016 https://www.wasteminz.org.nz/projects/love-food-hate-waste/, https://lovefoodhatewaste.co.nz) and Canada - launched 2018 http://www.canadiangrocer.com/top-stories/love-food-hate-waste-campaign-launched-in-canada-82020, http://www.lovefoodhatewaste.ca and Sustainability Victoria in 2018 https://thecitylane.com/love-food-hate-waste-encourages-victorians-to-rethink-food-waste/, https://www.sustainability.vic.gov.au/campaigns/love-food-hate-waste
R2	SUD (some MUD) – recycle/reuse (various treatments & home reuse)	FW (part) GO FW (part) FW (most) PW FW (all) PW	Caddy/hand Caddy/hand Caddy/hand Tongs & compostable bags Caddy/hand tongs & compostable bags	Composter >compost Worm farm >worm wee & casts Bokashi bucket >? Pet waste composter >? Solar composter >compost	    	**COMPOST REVOLUTION** In 2009 an intensive year-long trial of home composting education was conducted across Woollhara, Waverly and Randwick councils. The trial resulted in the very successful 'Compost Revolution' program launched Australia wide in 2012. The Compost Revolution program promotes the use of home composting/worm farms systems to help reduce food waste passing to landfill. Participating councils provide reduced rates on a range of home systems (i.e. composting, worm, bokashi, pet waste composting) and the initiative provides access to a website and online tutorials. The original program was found to have significant additional effects (i.e. increased recycling).	https://compostrevolution.com.au/about/ https://compostrevolution.com.au/?gclid=EAIaIQobChMIzv2b__mC4QIVSSUrCh3LxwCQEAAYASAAEgKyx_D_BwE https://reduceyourfootprint.com.au/media/uploads/attachments/Sydneys_Compost_Revolution_Lauren_Michener_print.pdf
R3	SUD & MUD	FW (most)	caddy	Dehydrator/ composter > dried organic material used at 1:11 with soil		**HOME DEHYDRATOR** After success in providing commercial dehydrators Food Cycle Science (FCS) in the US released the home Food Cycler in 2014. The current FC-30 version mini dehydrator has a capacity of 1 kg. It grinds, sterilises and reduces waste by up to 90% converting kitchen food scraps, including small bones and meat, in 3 hours. The units, requiring filters to be replaced every three months, require no water, vent or drain. The 500 W units use approx. 1 kW each cycle. They retail for less than USD 400 (incl a spare filter etc.) plus postage. According to the website the material needs to be left for over a week and then added to soil at a ratio of 1:11. In Australia, Perth based ZeroWaste Systems (selling both residential and commercial systems) are selling SmartCara a similar home dehydrator unit for approx. AUD 850. ClosedLoop appear to be bringing out a new version of their home dehydrator (Cloe) shortly.	**US** FCS https://www.globenewswire.com/news-release/2014/02/25/1227910/0/en/Food-Cycle-Science-Debuts-Residential-Indoor-Composting-Solution.html https://www.nofoodwaste.com https://www.nofoodwaste.com/pages/faq **Australia** Smart cara http://www.zerowastesystems.com.au/domestic review (https://ekko.world/smart-cara-food-waste-processor-review/203845) Cloe (seems to be updating unit) https://closedloop.com.au/home-composter/
R4	SUD	FW (most) Animal waste	caddy	AD Biogas & bio-slurry fertiliser		**HOME ANAEROBIC DIGESITON (AD)** After initial investigations the Homebiogas company was set up in 2012. The prototype home AD system was tested in Palestine in 2014/15 and the first generation product released commercially in 2016. The second generation product is now available/used in over 90 countries from the USA to Kenya. Working best in day/night temperatures above 15 deg C, for every kg of food waste put into the AD unit about 200 litres of biogas is produced, enough for approx. one hour of cooking. Up to 6 litres of food waste and 20 litres of animal waste can be put into the system per day (combined if needed) and produce up to 2 hrs of cooking time per day on a high flame. Delivered in a box for home assembly the units, including a stove, currently cost approx. USD 650 plus postage.	Homebiogas https://www.homebiogas.com/Blog/55/Home_Biogas_Systems_in_Australia
R5	SUD	FW & WW		AD Biogas& digestate		**HOME AD WITH TOILET** A bio-toilet kit is also now available with the Homebiogas AD unit and stove. Using a 1.2 litre per flush toilet the system can produce up to 300 litres of gas using the toilet as the only feedstock. A combination of food waste and toilet waste can be input to the system. The AD kit, stove and toilet cost approx. USD 890 plus packaging.	Homebiogas https://www.homebiogas.com/Products/HomeBiogas_Toilet
	COMMUNITY SCALE						
R6	SUD & MUD (community fridge)	FW (part)		Fridge		**COMMUNITY FRIDGE** Edventure: Frome, a school for community enterprise, challenged a group of 9 young adults to tackle food waste in their local town. Their solution, with support from the local council, was to set up the UK's first community fridge to share unwanted food including anything except raw meat, fish or eggs or home cooked food. Anyone can add or take food from the fridge. Similar shared facilities have been set up in the UK (London), Spain and Germany.	Frome, UK http://www.wehatetowaste.com/community-fridge-frome-food-waste/ London market fridge http://www.bbc.com/news/39642662 Solidarity fridge, Galdakao, Bilbao, Spain https://www.theguardian.com/world/2015/jun/25/solidarity-fridgespanish-town-cut-food-waste-galdakao Berlin, Germany http://www.dw.com/en/food-sharing-initiative-battles-berlin-authorities-over-closedcommunity-fridges/a-19042114 & https://www.dw.com/en/in-spain-a-shared-refrigerator-and-a-crusade-against-food-waste/a-18677642

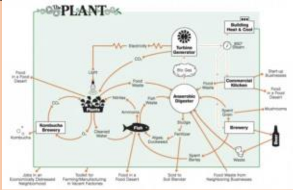
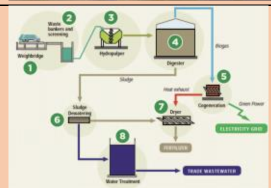
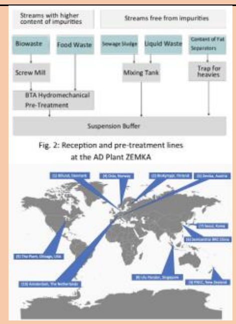
NO.	SECTOR	STREAMS	COLLECTION TRANSPORT	TREATMENT/ OUTPUT	IMAGES	DESCRIPTION	REFS
R7	SUD & (some MUD) (donation)	FW (part)		Carts		**GROW FREE CARTS** Similar to the Frome community fridge concept, grow free carts are a sharing idea that originated in Adelaide. It enables people to gift produce to the wider community and allow them to access what they need with no need for reciprocation or acknowledgment. Now available across Australia and indeed many other countries with an interactive map enabling people to participate.	Australia (similar concept to above – but broader) http://www.shareadelaide.com/food
R8	SUD & MUD (compost huts)	FW (part)	Caddy	Compost		**COMPOST HUTS** Based on the successful system set up in Hernani, Spain, Inner West Council trialled compost huts in 2017 in two locations for 6 months. The program engaged 120 SUDs & MUDs (the capacity of the compost hut units) in the vicinity of the huts. The service was provided through subscription and included both training and an access code to the huts.	IWC trials in 2017 (now stopped) https://yoursay.innerwest.nsw.gov.au/compost-hut-trials-for-tom-kenny-and-petersham-road-reserves Similar system to Spain (Hernani) – Youtube video in above link IWC ppt LGNSW "Rethink Food Organics" case study https://www.lgnsw.org.au/files/imce-uploads/90/Inner%20West_Rethinking_Food_Organics.pdf
R9	MUD	FW (part)	Caddy	Compost		**COMPOST COLLECTIVE** The compost collective program was trialled by Inner West Council in 2013. It involved providing support for composting on the common property of 96 apartment blocks with a total of 399 participating households. Residents were given free resources, on-site training and follow-up advice and support. Small MUDs of up to 12 units were found to work best. The program is still currently being offered to MUDs by IWC and expanded to an additional 20 apartment blocks in 2019.	https://www.lgnsw.org.au/files/imce-uploads/90/Inner%20West_Rethinking_Food_Organics.pdf IWC ppt gives different no.s (95 sites, 280hh) https://www.innerwest.nsw.gov.au/live/waste-and-recycling/zero-waste/food-waste/compost-collective
R10	Community garden	FW (part) GO		Compost	 	**COMMUNITY GARDENS** IWC, like many councils, has registered community gardens (currently 17 sites) in which composting and/or worm farms are commonly used to treat on-site organic waste and the potential to treat local community organics. More broadly the Australian City Farms and Community Gardens Network has set up an interactive map to help individuals locate community gardens nearby.	https://www.innerwest.nsw.gov.au/explore/parks-sport-and-recreation/community-gardens https://communitygarden.org.au/acfcgn-directory/
R11	SUD & MUD	FW (part) GO	Caddy	Worm farms Composter Chickens		**SHAREWASTE** Sharewaste is a mapping and communication app set up by an enthusiastic couple in the Inner West of Sydney, since around 2016, that enables people with food waste to connect with those with worm farms, composters and chickens in their local area that can potentially receive organic materials for local use/treatment. Now an international network with over 30,000 members	https://sharewaste.com
R12	MUD	FW (part)	Caddy	Worm farms >castings & juice (used at 1:10)		**MUD SHARED WORM FARMS** The City of Melbourne conducted a FW MUD trial in 2016 for two buildings. The Astoria building just outside the CBD trialled a ClosedLoop in vessel composter (see dehydrator below). The Hero building located in the CBD was chosen for a Hungry Bin worm farm system. The 150 apartment (with 1/3rd serviced), 13 storeys high Hero building was initially fitted with 9 bins, expanded quickly to 14, located in the building car park. The 37 participants that signed up to the trial (cbdnews 2016) were expected to weigh their food waste (scales near bins), scan their caddy and send the results to the City of Melbourne council (Christie and Waller 2016). The Hero Owners Corporation purchased an array of bins after the trial had finished in mid 2016 and supported on-going maintenance of the worm farms (for at least 12 months) through wormlovers. Participants used outputs for their balcony plants (cbdnews 2016; wormlovers). In 2016 a council in Southeast Melbourne (Stonnington) trialled worm farms in 3 low density apartment blocks with 11, 12 and 40 flats, positioned within shaded areas of their respective garden areas. These had 1, 2 and 1 bins installed respectively (Christie and Waller 2016). 24 participants took part in the trial (…a3.pdf). The success of these trials and additional trials in 2017/18 has led to an apartment composting program.	City of Melbourne trials https://apo.org.au/sites/default/files/resource-files/2016/07/apo-nid191906-1217556.pdf https://cbdnews.com.au/our-building-has-worms/ https://www.tandfonline.com/doi/abs/10.1080/00958964.2018.1509289?journalCode=vjee20 https://www.wormlovers.com.au/our-hero Stonnington trials https://www.stonnington.vic.gov.au/Lists/Media-Releases/Reducing-food-waste-at-apartment-buildings-through-communal-worm-farming?BestBetMatch=trial|37b7066e-ebb3-452d-b232-0db493208d83|cb64c12d-89d6-4de4-84a9-19ac1af9491d|en-AU https://www.stonnington.vic.gov.au/files/assets/public/live/sustainability/apartment-compost-case-study-a3.pdf https://www.stonnington.vic.gov.au/Lists/News/Apartment-buildings-trial-innovative-solutions-to-recycle-food-waste?BestBetMatch=trial|37b7066e-ebb3-452d-b232-0db493208d83|cb64c12d-89d6-4de4-84a9-19ac1af9491d|en-AU This has led to an ongoing program for flats to participate in communal composting and worm farm systems. https://www.stonnington.vic.gov.au/Live/Waste/Other-Waste-and-Recycling-Opportunities/Food-Waste-Recycling/Apartment-Composting-Program
R13	MUD	FW	Caddy/bins	Dehydrator/decomposer/ Composter (20%) 24hrs > dehydrated material needs to mature for a few weeks and can then be used like chicken manure.		**MUD IN-VESSLE COMPOSTER/DEHYDRATOR** The Astoria building just outside Melbourne was one of two MUDs chosen for a FW trial (see Hero building above that trialled a worm farm) in 2016. The Astoria building was chosen to test a 100 kg/day capacity ClosedLoop in-vessel composter (dehydrator) located in the carpark of the 9 storey building with 85 apartments. Residents were asked to put FW in bins on each level of the car park. The building manager would then feed the FW into the dehydrator system each morning, to minimise H&S issues with residents. Participants were asked to estimate the weight of their FW and text/e-mail the information to the City of Melbourne council.	Closed loop system in North Melbourne trial https://apo.org.au/sites/default/files/resource-files/2016/07/apo-nid191906-1217556.pdf https://www.tandfonline.com/doi/abs/10.1080/00958964.2018.1509289?journalCode=vjee20
R14	MUD	FW (part)	Caddy	Compost		**MUD ROCKET COMPOSTER** A 2 year FW composting trial was set up in a low/medium density housing estate by the London Borough of Camden (Maiden Lane Estate) in 2009. The Rocket Composter A900 had a capacity of 875kg/week. Approx. 200-250kg/week of FW was collected by residents. When the trial finished the resident community took over the running and management of the system and launched FoodLoop a social enterprise scheme which ran for 3 years. The output was used to grow food on the estate and also sold as fertiliser. The system still appears to be running for the current 479 households on the estate under a rebranded version of the FoodLoop volunteer system.	http://www.cultivatingcommunity.org.au/wp-content/uploads/2018/01/Exploring-In-Vessel-Food-Waste-Processing-Units_update2018.pdf (p19) https://www.researchgate.net/publication/315755649_Food_Loop_-_A_technical_research_report_for_the_Department_for_Environment_Food_and_Rural_Affairs http://cargocollective.com/foodloop/About-Foodloop
	REGIONAL/ CITY SCALE						
R15	SUD & MUD rewards scheme (meal planner & sign up to FW recycling bin system)	FW (part)				**GREENREDEEM INCENTIVE SCHEME** In 2015 the Royal Borough of Windsor & Maidenhead (RBWM) partnered with Greenredeem, a company specialising in developing rewards schemes for everyday green actions. RBWM set up a Food Waste Recycling initiative to encourage residents to recycle food and use leftovers more effectively, 'love your leftovers'. The scheme is an extension of an existing initiative. As part of the scheme residents receive a years supply of caddy liners and free outdoor recycling bins on request. All residents can be rewarded for recycling food waste, checked through weighing of their bins upon collection, by going to the Greenredeem website and pledging to recycle their food waste. Points earned for recycling food waste can then be converted to vouchers for local businesses such as coffee and leisure outlets. Various other UK reward schemes are discussed in Giorgi et al 2016. A similar reward program, Randwick Green Money, ran as a two year trial (2013 to 2015) on dry recyclables	See Greenredeem PUP R9 (links broken) https://www.greenredeem.co.uk/press-releases/press-releases/the-royal-borough-and-greenredeem-boosts-food-waste-recycling-scheme- https://www.greenredeem.co.uk Giorgi et al 2016 http://www.randwick.nsw.gov.au/about-council/news/news-items/2015/march/green-money-trial-ends-redeem-points-by-31-march-2015

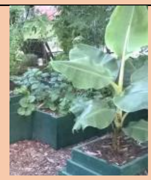
NO.	SECTOR	STREAMS	COLLECTION TRANSPORT	TREATMENT/ OUTPUT	IMAGES	DESCRIPTION	REFS
R16	MUD FW collection (city scale)	FW (most)	Caddy>bin	Various animal feed, compost & AD		**PAY AS YOU TRASH (PAYT)** Food waste to landfill has been banned in Korea since 2005. In 2010 to 2012 a pilot of volume based charging involving 144 local regions was rolled out. Now virtually every residential complex is involved. Since 2013 it has been compulsory to use biodegradable bags. The PAYT' scheme varies. 1) Dispose of food waste in garbage bags with different sized coloured bags bought from grocery stores (with various $ - a 10L bag cost <$1), 2) Local government distributes food waste bins to customers. When disposing of food waste residents must stick a chip or sticker (bought from grocery stores) on the bin otherwise it isn't collected – a garbage truck collects the bins only if chip/sticker present, 3) Radio frequency identification (RFID) tag – RFID bin with magnetic card reader. Each household has a card that will open a bin, when use centralised bins their waste is weighed and the household charged monthly. RFID bins are approx. $1500 each and can cater for 60 households. Due to various schemes including the PAYT schemes South Korea has continued to reduce food waste (currently 95% from only 2% in 1995). There are now 6,000 automated weighing bins fitted with RFID in Seoul. Residents are urged to reduce the moisture in their food waste to reduce costs. The waste collected is treated in different ways depending on location. In one on the edge of Seoul the biodegradable bag schemes are squeezed at the processing plant to remove moisture which is used to create biogas. The dry waste is further dried and powdered and used as animal feed. In other locations such materials are turned into fertiliser helping to drive urban farms which the government is providing 80-100% of the start-up costs. There are now over 170 hectares of farms manly squeezed between apartment blocks. Many Koreans also choose to create home compost. Similar PAYT schemes have been in place in Germany and Belgium since the mid 1990s.	Korea http://www.legco.gov.hk/yr12-13/english/sec/library/1213inc04-e.pdf http://www.odditycentral.com/news/unique-pay-as-you-trash-system-helps-south-korea-cut-food-waste.html http://www.straitstimes.com/asia/east-asia/culture-shock-over-south-koreas-mandatory-recycling-of-food-waste https://www.weforum.org/agenda/2019/04/south-korea-recycling-food-waste/ https://www.intelligentliving.co/south-korea-zero-food-waste/ See RC6&7 Milan and San Francisco for (residential and non-residential programs Similar pay as you throw (PAYT) examples. County of Aschaffenburg, Germany PAYT since 1997 (Morlok et al 2017) www.mdpi.com/2079-9276/6/1/8/pdf Belgium PAYT, since 1995 http://www.regions4recycling.eu/upload/public/Good-Practices/GP_OVAM_PAYT.pdf
R17	MUD FW collection (parts of councils)	FW (part)	Caddy>bin	AD > bioenergy & digestate fertiliser		**FOOD ONLY ORGANICS (FOO) MUDS COLLECTION** IWC first commenced a food only organics (FOO) service in the former Leichhardt council area for MUDs in 2008 (Herriman et al 2014). The service is now available for MR blocks with 10 or more units and includes provision of free caddies and bags. The service provided to 220 MUD properties (5,200 units) removes the FW for treatment at the EarthPower AD system to generate bioenergy and digestate fertiliser. Randwick City Council food scraps trial commenced in 2013 on 90 blocks of MUDs (5,000 units) with the view to roll-out to all MUDs and SUDs in future as part of their Waste Management Strategy. There have also been numerous UK trials/programs undertaken by WRAP/UK councils including the Swansea case study (2011– ongoing)	Leichhardt current https://www.innerwest.nsw.gov.au/live/waste-and-recycling/household-waste/your-bins/food-waste Leichhardt trial https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/wastegrants/18p0751-leichhardt-fogo-casestudy.pdf IWC (Helen Bradley e-mail awards doc Sept 2019) Several trials in Sydney (i.e. Randwick) http://www.randwick.nsw.gov.au/services/rubbish-and-recycling/household-rubbish/food-scraps-bin UK http://www.wrap.org.uk/content/recycling-collections-flats-food-waste-collections
R18	SUD FOGO collection	FW (part) GO	bins	> compost		**FOOD ORGANICS GARDEN ORGANICS (FOGO) SUDS COLLECTION** As at 2019 there are over 40 councils in NSW operating FOGO services. Only one metro council, Penrith, is offering a FOGO service (for SUDs), which it first initiated back in 2009. This is in part due to the historical lack of processing facilities available to metro councils compared to regional councils and other perceptions on the difficulties. Lismore council was one of the first councils in Australia to introduce domestic collection of food organics. Rolled out in 1999/2000 it has been extremely successful. Collection of food waste is available to all properties with the kerbside garden organics service. As at 2012, 11,000 households were serviced and 4,000 caddies (with liners) provided free of charge. A three bin service commenced in 2006 to separate paper/cardboard. Food waste caddies were introduced in 2009 and acceptance of compostable nappies in 2012. A one off caddy and roll of compostable bags are provided free of charge, available for pick up at council. Bags for subsequent purchase. The waste is taken to the city waste processing facility where it is mulched and shredded, composted in rows, screened to remove plastics/inorganics and converted to rich compost for resale. 14 kg/household/week of FOGO is collected with auditing of the residual bins showing 92% capture rate of organics and very low contamination rates of 1%.	NSW https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/business-government-recycling/food-organics-and-garden-organics Penrith https://www.environment.gov.au/system/files/resources/8b73aa44-aebc-4d68-b8c9-c848358958c6/files/collection-manual.pdf https://blog.mraconsulting.com.au/2017/07/27/laying-out-the-fogo-benefits-and-challenges/ Lismore https://www.environment.gov.au/system/files/resources/8b73aa44-aebc-4d68-b8c9-c848358958c6/files/collection-manual.pdf http://www.northernriverswaste.com.au/cp_themes/default/page.asp?p=DOC-RPK-55-48-21
R19	MUD	FW (part) UCO/FOG	Insinkerator > tank	AD WWTP AD		**IN-SINK-ERATORS** Malmo in Sweden has a population of 335,000. FW collection has been an expectation since 2012. 93% of the 26,000 SUDs participate in FW collection which is free (residual waste charged). 90% of the MUDs participate and pay for FW collection (as do businesses) but only 1/3rd of the cost of the residual waste collection to provide an incentive (Heinrich 2018). Due to hygiene, council interest, lack of space and desire to reduce heavy vehicle movements in dense areas a pilot was conducted from 2012 to 2014 in Fullriggaren (Western Harbour) Malmo. The pilot included an area of 16 buildings with a total of 614 flats. Using 2 separate tanks (east and west) the pilot tested the use of in-sink-erators feeding into a tank system constructed similar to a grease trap (i.e. designed to separate grease, food waste sludge and liquid) with the liquid discharged to sewer and the other materials emptied approximately every 4 weeks for treatment in an AD plant to produce biogas and digestate. The west system had an additional pre-settler tank. The systems, still in use, were found to collect 33-55% of the FW. 22-33% of the FW passes to sewer in a dissolved/semi dissolved state. 37% still ends up in residual waste. (Bissmont et al 2015). A similar system is being considered for potential use at the multi billion dollar mixed use Barangaroo development to aid in dealing with the significant volumes of food waste being produced.	Malmo, Sweden- (asa.davidsson@chemeng.lth.se, Mimmi.Bissmont@vasyd.se, Marie.Castor@vasyd.se) https://beyondfoodwaste.com/malmo/ (no ref to tanks – background) https://kundoc.com/pdf-technical-evaluation-of-a-tank-connected-food-waste-disposer-system-for-biogas-p.html https://www.sciencedirect.com/science/article/pii/S0956053X12004618 http://ecosaver.se/onewebmedia/Energiforsk001.pdf (another new report 2015)
R20	SUD & MUD In-sink-erator - sewer	FW (part) UCO/FOG		WWTP (AD) > biogas & digestate		**IN-SINK-ERATOR TO OFF-SITE AD** From 2014 to 2015 InSinkErator conducted a trial in a block of flats in Calgary (the Conservatory) to test reduction in food waste passing to municipal waste as well as other research. Fifty in-sink-erators were installed (40 new and 10 upgrades) with 15 units not participating. The in-sink-erators in combination with educational material were found to assist in reducing food waste to municipal waste by 60%, from >1kg to <0.5kg per household/week. Similar research was conducted by InSinkErator in Philadelphia, Chicago, Milwaukee, Tacoma and Boston on over 500 homes where the waste water treatment process at the time included AD. The research highlighted potential benefits of wider roll out of in-sink-erators and resulted in various outcomes including installation of 3,000 disposal units in public housing in Boston and a building/plumbing code amendment in Philadelphia in 2016 enabling disposer installation in buildings as an option for waste management.	Calgary, Canada https://www.cochranetoday.ca/local-news/industry-leader-raises-concerns-about-proposed-garburator-ban-in-cochrane-1451680 5 cities in the US https://www.aham.org/AHAMdocs/Main%20Site/InSinkErator.pdf http://agendaminutes.calgary.ca/sirepub/cache/2/kwf1ktjdzetecvvsq4a0mlnw/5176660422017085613902.PDF http://images.insinkerator.com/mktg/environmental/5-CityInfographic.pdf
R21	SUD & MUD	UCO	Caddie/public collection point			**RESIDENTIAL UCO COLLECTION** UCO and FOG when disposed of down the drain are recognised as major contributors to sewage system blockages which can cost millions of dollars in repairs annually. The majority of countries in the EU do not have UCO recycling points for the residential sector. However, countries such as Austria, Belgium and the Netherlands have set up successful country wide residential UCO collection systems. Austria currently collects approximately 1 kg/capita/a. Belgium's system, over 12 years old, is the best developed system in Europe, supported by regulation. In 2014 they collected 8,300 MT of oil (approximately 0.73 kg/capita). In the Netherlands a voluntary initiative is supported by an association that coordinates partners within the supply chain from collectors and biodiesel producers to local authorities and sewage companies, with the UCO used to make biodiesel. In the Netherlands 3,660 MT of UCO was collected in 2015 (approximately 0.21 kg/capita). The Netherlands system collecting approximately 30% of estimated collectable residential UCO whilst Belgium, with their regulated system, captured 64%. Across Europe the UCO potential varies significantly due to culinary habits with Belgium, the Netherlands and Spain being higher per capita UCO producers than Scandinavian countries. Various approaches have been used with most enabling residents to take containers to marked drop-off recycling points. These being highly	Europe http://www.greenea.com/publication/and-do-you-recycle-your-used-cooking-oil-at-home/

NO.	SECTOR	STREAMS	COLLECTION TRANSPORT	TREATMENT/ OUTPUT	IMAGES	DESCRIPTION	REFS
						frequented places such as shopping malls, open-air markets, parking lots, schools, and streets. Advertising campaigns often play a central role. In Belgium along with a national campaign involving a designed character (the Oil Ghost) they arrange collection months in which households bringing in a litre or more enter a lottery for movie tickets, bikes or a trip to New York. In Italy they run education campaigns and collaborate with schools to collect the most oil per student.	
MIXED							
RC1	All Regulation - ban	FW/ organics				**REGULATION BANNING ORGANIC WASTE TO LANDFILL** Driven initially by community group concerns about the construction of waste management facilities, Korea, focused on the 3Rs (reduce, reuse, recycle). By 1995 a fee system was introduced for waste generation to try to restrict waste volumes increasing at the same time as the introduction of separated collection and regulations on packaging. By 2005 organics were no longer accepted at landfills and had to be recycled. This has driven significant innovation in Koreas organic waste management practices and enabling food waste recycling to increase from 2% in in 1995 to current levels of 95%.	Sakai et al 2011. https://link.springer.com/article/10.1007/s10163-011-0009-x https://www.intelligentliving.co/south-korea-zero-food-waste/
RC2	SUD & MUD & commercial neighbourhood avoidance App	FW (part)		> meals		**CAFÉ APP** In 2016 Food for All started a pilot with 30 restaurants in Cambridge Massachusetts. The app allows signed up restaurants and customers to connect whereby signed up customers search for food deals (typically between 50 to 80% off retail price) close to their desired location and place an order for the registered restaurants leftovers (foods that did not/will not sell by the end of the day). The customer then goes and picks up the food at the designated time. Food for All used crowd funding to advance the App and expand to other areas such as Boston and New York City. A similar "Y waste" app for those experiencing food insecurity was launched in Sydney in 2017.	https://www.treehugger.com/green-food/app-reduces-food-waste-offering-restaurant-leftovers-80.html https://foodforall.com https://www.sbs.com.au/food/article/2018/09/03/y-waste-app-connects-customers-end-day-surplus-food-outlets https://ywasteapp.com
RC3	SUD, MUD & commercial (feed pets/backyard animals/ animals)	FW (part)		> animal feed		**FEEDING ANIMALS** Feeding animals including pets, backyard animals and livestock with food scraps/waste has been a common practice globally for centuries. Often with the beneficial outcome of protein rich eggs in terms of chickens or meat with respect to animals such as pigs. However, in recent years the practice has declined with laws and regulations being put into place in many countries restricting the use of animal products as inputs to animal/livestock feed. This was instigated due to several serious disease outbreaks such as foot and mouth in pigs and bovine spongiform encephalopathy (BSE)/mad cow disease in cattle. There have also been warnings from vets that feeding pets food scraps can lead to serious health issues such as pancreatitis, colitis and gastroenteritis as well as the risk of obesity in dogs. In NSW no products containing meat should be supplied to feed stock. Feeding any animal materials such as meat or bone meal, fish or feather meals, or any food potentially contaminated with animal material to ruminant animals (cattle, sheep, goats and deer) and pigs is banned to help provide insurance against the spread of serious animal diseases. However, large volumes of materials are used for animal feedstock from commercial properties, such as over 750 tonnes/a of fish/oyster residue from the Sydney Fish Markets regularly collected, refrigerated and transported off site for conversion to poultry feedstock free of charge. In 2014/15 Woolworths reported that half of its 1,000 stores across the country have a farm donation program, resulting in 40,000 tonnes of food being sent to farms for animal feed, its most significant diversion activity. In 2016, 65% of stores were involved in such programs.	https://www.phoenixnewtimes.com/restaurants/table-scraps-how-animals-help-us-humans-combat-food-waste-11339861 https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/waste/reduce-food-waste-business-fact-sheet-160375.pdf?la=en&hash=F826FCD08F59E60001523B7879DA39B79EF707DA https://www.researchgate.net/publication/321080982_Pyrmont-Ultimo_Precinct_PUP_Organics_Management_Scoping_Study Castrica et al 2018. Pet food as the most concrete strategy for using food waste as feedstuff within the European context: a feasibility study. https://www.researchgate.net/publication/325800385_Pet_Food_as_the_Most_Concrete_Strategy_for_Using_Food_Waste_as_Feedstuff_within_the_European_Context_A_Feasibility_Study http://www.helenlewisresearch.com.au/wp-content/uploads/2017/07/EPA_Food-waste-report_FINAL_2017-07-07.pdf Woolworths (2016a) *APC Annual Report*. www.packagingcovenant.org.au/data/AnnualReports2016/Woolworths Limited_AR_2016.pdf
RC4	SUD & Commercial neighbourhood FW collection	FW (part)	Bike/van	Compost Worm wee & casts		**SUBSCRIPTION FOOD WASTE PICK-UP SERVICE** Healthy Soil Compost started as a hobby in 2014/15, progressed into a one man business on a bike, then to an additional 4 part time bikers and since 2016 has used a motor vehicle as well. Food waste is collected from houses and commercial restaurants in various suburbs in Chicago. A container with a lid typically 5 gallons is provided on sign-up. Charges vary with frequency of pick-up – from monthly $20 to weekly $40. In one year, the entrepreneur collected 60,000 lbs of food waste on his bike. The waste is either composted or treated by a worm farm depending on location and time of year through various partnerships. Customers also have the opportunity of buying back the compost/soil. Earth Bucket is the first residential and commercial food scrap pickup service in Sydney, also accepting waste from schools. It provides a similar service to that of Chicago.	Chicago, US http://www.healthysoilcompost.com Residential pickup http://earthbucket.com.au
RC5	SUDs, offices & institutional buildings	FW (part)	Truck	Maggots > animal feedstock		**GOTERRA MAGGOT FARMS** In 2016, Goterra, a start-up waste management company was founded in the ACT. Taking food waste initially just from two or three offices the company now processes waste from more than 400 homes, the local hospital, businesses and several state and federal government offices. The innovative process feeds the waste to a specific breed of maggot, before turning those maggots into protein-rich feed for livestock. The insect farm is run in compact sea container units robotically, providing flexibility for standalone units in future applications, which the founder believes could be run in places like shopping malls to reduce waste and produce valuable animal feed. The feed currently being fed to chickens, pigs, aquaculture and pets.	https://www.goterra.com.au https://www.smartcompany.com.au/startupsmart/news/goterra-robotic-maggot-farms/ https://www.youtube.com/watch?v=xEka0FpmR5k https://www.youtube.com/watch?v=UJtj72-X3A0
RC6	SUD, MUD & commercial FW and GO collection (city scale)	FW (part) GO	Caddy>bin	Compost		**CITY-SCALE REGULATION BANNING ORGANICS TO LANDFILL** Approx. 150,000 tons of FW is collected from households and businesses in San Francisco per year and sent along with other organics to a commercial composting facility approximately 60 miles to the north west of the city for treatment. Bins can be collected anywhere from weekly to daily depending on the needs of the property, with caddies provided to help collect the waste from kitchen areas. Incentives for residents include differential pricing (i.e. composting removal is a tenth of the cost of the normal garbage bin), with repeated contamination resulting in a charge of 50%. Credit incentives are provided to businesses. In 2009 the city introduced a mandatory recycling and composting ordinance making it compulsory for residents and non-residents to recycle organics with associated fines for non-compliance of USD100 upon the third identified occurrence (warnings being provided before this). Challenges associated with single chutes in MUD buildings have resulted in modifications to the language in building codes for new buildings (i.e. requiring multiple chutes or diverters) and requirements for existing buildings to provide areas for three bins and/or close off chutes. A multifaceted education program and single organics service provider have also contributed to the success of the program.	San Francisco, US https://beyondfoodwaste.com/what-makes-san-franciscos-food-recycling-program-successful/ https://www.cnbc.com/2018/07/13/how-san-francisco-became-a-global-leader-in-waste-management.html

NO.	SECTOR	STREAMS	COLLECTION TRANSPORT	TREATMENT/ OUTPUT	IMAGES	DESCRIPTION	REFS
RC7	SUD, MUD & commercial FW collection (city scale)	FW (part)	Caddy>bin	AD		**CITY-SCALE REGULATION BANNING FOOD WASTE TO LANDFILL** Milan, a highly urbanised city of 1.3 million with 80% of residents living in MUDs, launched an organics program in late 2012 after two failed attempts. The program was rolled out over 4 phases with the last in mid 2014. The roll out process involved investigating and surveying each of the four areas of the city, closing building waste chutes to force residents to deposit food waste in building bio bins provided, checking where bio bins could be located within private premises etc. and then distributing bio bins and starter kits (with leaflets on the program, a vented caddy, bio bags, access to website and call centre for advice etc.). After implementation the program resulted in 140,000 tons of food waste being collected and treated per year predominantly (70%) from residents. The food waste being taken to a large AD facility outside the city creating bio energy and digestate fertiliser. Energy is used to power the on-site plastic reprocessing plant and more recently to assist in powering the waste truck fleet. Prior to the scheme food waste recycling was only 23 kg/person/year. With the scheme this has increased to 90kg/person/year with approx. 86% diversion of food waste and only 14% in residual waste. Legislation requires that no food waste passes to landfill and fines are applied (50,000 in 2016/17) including the whole MUD building if contamination is found. Additional programs are being rolled out including market biowaste separation and new waste tax reductions for organisations that donate surplus food to charities.	Milan, Italy https://beyondfoodwaste.com/milan-achieves-world-class-separate-food-waste-collection/ http://www.recyclingwasteworld.co.uk/in-depth-article/the-italian-mode-how-italy-leads-the-way-in-europe-in-separate-waste-collection-systems/71126/ https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study https://www.youtube.com/watch?v=zSjBbp-Q3lU https://resource.co/article/setting-trend-milans-recycling-success-12837
RC8	MUD & commercial (suburb scale)	FW	Dry vac	Compost		**DRY VACUUM ORGANICS REMOVAL** Beginning in the 1980/90s and developed in several stages the Hammarby development in Stockholm Sweden of 11,000 homes and associated facilities is now complete. It combines multiple environmental principles to represent one of the first urban green developments. A key component is the vacuum system adopted which transports multiple waste streams (general waste, food/organic waste and paper waste etc.) underground. Developed over several decades different approaches have been used, with the automated underground stationary vacuum system being a core component. The waste, from hundreds of inlets in multiple locations across the phased development is put into dedicated repositories. The waste is discharged through a single piped system at 90km/hr to areas where the waste is sorted for processing. The food/organic waste is composted into biosolids and used as fertiliser. Other areas in Sweden such as Linkoping use a coloured bag system and an automated optical sorting system to sort the waste ready for processing. Australia's first large scale use of the vacuum system will be in the CBD at Maroochydore in the Sunshine Coast including 2000 flats.	Hammarby, Sweden (combination of res and non res parts of system) http://www.solaripedia.com/files/719.pdf Multiple countries including UK Wembley site https://nctce.com.au/wp-content/uploads/2019/03/Envac_brochure-11-16-Lee-Gyuhwang.pdf Maroochydore (sometimes says 2 and sometimes 3 fractions) https://www.sunshinecoast.qld.gov.au/Council/News-Centre/Maroochydore-City-Centre-leads-waste-revolution-210916 https://www.sunshinecoast.qld.gov.au/Council/Planning-and-Projects/Infrastructure-Projects/Automated-Waste-Collection-System https://www.sunshinecoastdaily.com.au/news/where-the-cbds-underground-waste-will-end-up/3362003/ https://www.envacgroup.com/casestudies/maroochydore-sunshine-coast/ (says 2000 flats)
RC9	SUD & MUD & Commercial (markets)	FW (part)	Caddies	Compost & Worm farm		**MARKET FOOD WASTE COLLECTION & TREATMENT** Green City Market in Chicago is a year round farmers market with 175,000 visitors a year. The markets have operated in various forms since the late 1990s. The market currently partners with WasteNote Compost and Healthy Soil Compost and the Resource Centre to treat food waste from the market. The recycling enables the market to reduce their waste from 30 bins to 6 per day. The "Compost Center" tent at the market is a centralised waste disposal / recycling area manned by staff to assist people to minimise contamination. The market now also provides a household compost drop off service. Householders can bring in their food scraps including dairy and meat in a bucket or container (tight-fitting lid advisable) at a cost of $3/drop-off (max 5 gallons). The materials are then trucked to different locations including the Resource Centre (non-profit) composting facility on the south side of the city. Compost is used to grow food etc.	Green City Market, Chicago, US - Drop off at markets http://www.greencitymarket.org/programs/program.asp?id=12 http://www.greencitymarket.org/cmsfiles/compost_info.pdf
RC10		FW, FOG, GO	Wet vacuum toilets	AD		**HAMBURG COMBINED VACUUM/AD SYSTEM** The KREIS project focuses on a new combination of renewable energy provision with innovative wastewater treatment, the "Hamburg Water Cycle®" (HWC) which will be applied in the Jenfelder Au neighbourhood in Hamburg. HWC includes a separate collection of rainwater, greywater and blackwater. Vacuum toilets are used to concentrate the blackwater. Biogas will be produced from the blackwater in an AD process together with co-substrates (i.e. GO, FOG). The blackwater will be transported to the AD pre-treatment facility via a vacuum system. Construction of water systems started in 2013, and commercialization of houses is planned to be finished in 2018.	https://energsustainsoc.biomedcentral.com/articles/10.1186/s13705-015-0057-5 Hertel et al 2013 - Biogas and nutrients from blackwater, lawn cuttings and grease trap residues—experiments for Hamburg's Jenfelder Au district *Biogas and nutrients from blackwater, lawn cuttings and grease trap residues—experiments for Hamburg's Jenfelder Au district*" (https://tore.tuhh.de/bitstream/11420/1610/1/s13705-015-0057-5.pdf) https://www.hamburgwatercycle.de/en/hamburg-water-cycler/ [Note from co-author Ina Koerner i.koerner@tuhh.de. *Following contacts may be helpful to you: Mr. Meulman is running a nice system in Netherlands and built one in Sweden. And then please contact Herr Buettner. He is responsible for an AD plant for blackwater in Hamburg, which was opened today! The combination with food waste is not yet done. (Legislative burdens ae a problem, but I hope for the future...). And for our actual project on small scale AD of food waste please have a look at the DECISIVE webpage (*www.decisive2020.eu*). In D3.6 the system in Lübeck is described (but the AD is not running, only vacuum toilets).*]
						NON-RESIDENTIAL (COMMERCIAL)	
NR1	Commercial avoidance Food rescue	FW (part)		> food redistribution		**FOOD RESCUE** Oz Harvest was established in 2004 and was the first perishable food rescue organisation in Australia. It collects over 180 tonnes of excess food from over 3,500 donors including hotels, airports, wholesalers, farmers, corporate events, catering companies, shopping centres, delis, cafes and restaurants. The rescued food is delivered free of charge, using the OzHarvest fleet to >1,300 charities in Sydney, Adelaide, Brisbane, Canberra, Gold Coast, Melbourne, Newcastle and Perth to people in need. In more regional areas a food app has been developed to connect businesses with surplus food to charities in need of food relief. In 2017 Oz Harvest opened Australia's first rescued food supermarket. A pop-up market in Kensington available for as long as the temporary site was available. The concept, inspired by the world's first surplus supermarket opened in Denmark in 2016 (see below).	OzHarvest http://www.ozharvest.org/ https://www.ozharvest.org/what-we-do/our-story/ http://www.ozharvest.org/market/ Similar organisations FoodBank (https://www.foodbank.org.au/) Second Bite (http://secondbite.org/) Fareshare (http://www.fareshare.net.au/
NR2	Commercial/ distributor food waste avoidance	FW (part)		> food redistribution		**SURPLUS FOOD SUPERMARKETS & REDISTRIBUTION** There are numerous international examples of voluntary partnerships, on-line platforms & initiatives aiming to avoid food waste and help in redistribution. Food surplus supermarkets – The first, Wefood Copenhagen, Denmark, launched in 2016. One of the latest is in Helsinki, Finland to open in 2019 offering food at a 30-50% discount. Back-of-store – In the UK Sainsburys have been working with local charities to rescue unsold food since 1998. The Sainsbury's Cardiff supermarket store and charities Bawso and Cardiff Women's Aid for refugees have worked together by each charity collecting food on different days of the week and redistributing directly to refugee residents in Cardiff. There are numerous on-line platforms connecting surplus food generators and surplus food distributors (i.e. Phenix, Foodwe, FoodCloud). Foodshare commenced in 2012 in Germany and expanded to Austria and Switzerland. It includes the concept of shared fridges, now with >200,000 users on the network.	Food surplus supermarkets Wefood Copenhagen, Denmark (https://www.independent.co.uk/news/world/europe/denmark-food-waste-supermarket-we-food-copenhagen-surplus-produce-a6890621.html) Helsinki, Finland (https://newsnowfinland.fi/news-now-original/tackling-poverty-and-waste-new-helsinki-supermarket-offers-surplus-food-at-discount-prices) Back-of-store (http://www.wrap.org.uk/sites/files/wrap/02-Sainsbury%27s%20Case%20Study.pdf) Foodsharing.de (https://foodsharing.de/#wilkommen) (https://www.dw.com/en/food-sharing-initiative-battles-berlin-authorities-over-closed-community-fridges/a-19042114)
NR3	Commercial avoidance Bin Trim	FW (part)				**BIN TRIM** The Bin Trim program, funded by the NSW EPA Waste Less Recycle More initiative, has already assisted more than 28,000 businesses to reduce waste. The program aims to assist small and medium sized businesses to identify actions they can take to cut waste and recycle more, to assist in boosting profits. The program which focuses on all facets of potential avoidance and increased recyclables offers free or reduced cost waste and recycling assessments by a qualified assessor together with advice, a personalised action plan and access to potential rebate funding of between $1k to $50k to assist with the cost of recycling equipment. An online tool is also available as well as documented case studies.	http://www.epa.nsw.gov.au/managewaste/bin-trim.htm http://www.epa.nsw.gov.au/managewaste/bin-trim-tool.htm http://www.epa.nsw.gov.au/managewaste/bin-trim-case-studies.htm https://www.thefifthestate.com.au/waste/nsw-governments-bin-trim-program-slashes-hotel-waste-to-zero/

NO.	SECTOR	STREAMS	COLLECTION TRANSPORT	TREATMENT/ OUTPUT	IMAGES	DESCRIPTION	REFS
NR4	Commercial grocery stores Waste to water	FW (part)		Waste to water WWTP		**WASTE TO WATER** In 2013 Banana Joes Supermarket in Marrickville installed a Bio-Ez waste to water system. Food waste such as discarded fruit and vegetables from the supermarket are collected by staff on-site and added to the machine. The waste is shredded within the machine and specific microbes added to rapidly decompose the material before it is discharged to sewer thereby avoiding significant waste collection, transports and landfill disposal fees. Similar systems (i.e. PowerKnot) are used in the US for applications such as hotels, restaurants and food processing and are now available in Australia.	https://wastetowater.com.au https://www.youtube.com/watch?v=_xyuvBOhg3E PowerKnot USA http://www.powerknot.com/2012/11/28/big-river/ http://powerknot.com.au
NR6	Commercial grinder	FW (part)		Grinder Tank>AD		**COMMERCIAL FOOD WASTE MACERATOR TANK COLLECTION** In 2014 the Andover Whole Foods Market store in Massachusetts installed a Grind2Energy system, the first grocery store in the USA to do so. Food waste from the store including some paper/napkins is deposited into the grinder disposal unit via a bench which has electrical and plumbing connections. The food slurry is then pumped to a holding tank for regular collection. The food slurry is collected on a regular basis and taken to an AD plant for treatment at a local farm to produce energy and fertiliser. Grind2Energy has partnered with Whole Food Market stores and the system is now installed in 10 locations.	US http://www.grind2energy.com/news/case-studies/whole-foods-market-evaluates-grind2energy-system https://www.youtube.com/watch?v=fb5sQZbVDw4
NR7	Commercial grinder	FW (part)		Grinder Tank>AD or soil injection		**COMMERCIAL FOOD WASTE MACERATOR TANK COLLECTION & PAYT INCENTIVE SCHEME** In Australia, a similar pulping systems combined with a holding tank and subsequent transfer offsite for treatment is provided by Pulpmaster. A new system is being installed at the MarketPlace in Leichhardt, owned by Local Government Super and managed by JLL, to deal with the large volumes of waste generated at the shopping centre. The new pay-per-kilo system will complement the Pulpmaster system, with the concept being for food retailers at the centre to use the Pulpmaster system to help reduce their waste and only pay per kilo for what remains. Smartweigh machines will be installed and bins fitted with locked systems to help minimise unauthorised dumping and streamline the system. Within the food court bins will be modified to include organics disposal. The waste will be sent to the EarthPower AD plant.	Australia http://pulpmaster.com.au/products https://www.thefifthestate.com.au/waste/lgs-cracks-the-shopping-centre-waste-conundrum-starting-in-sydneys-inner-west/
NR8	Commercial vacuum	FW (part)	Wet vac	Dehydrator > biogas/composting		**SHOPPING MALL FOOD WASTE VACUUM SYSTEM & DEHYDRATOR** The Westfield Shopping Centre in Shepherd's Bush UK at 150,000 sqm is the largest shopping mall in London. The mall with 265 high end shops, 50 restaurants, spa, cinema, library and gym has over 27 million visitors a year. The expansion of the food court meant the need to upgrade the warewashing and food waste processing system. In 2016, to handle the more than 9,000 plates and bowls plus associated cups, glasses and cutlery a new system by Rendisk was installed (Rendisk Flex WasteDispo). A combination of conveyor/rack systems was installed for the plates etc. and a vacuum disposal system used to eliminate all internal transport of food waste was installed together with centrifugal dehydrator system to reduce food waste by up to 80%. The dry pulp is suitable for use in biogas/composting plants.	http://www.rendisk.com/application/files/5314/8161/9798/Brochure_Rendisk_Flex_WasteDispo_2016_DEF.pdf http://www.rendisk.com/news/news-2016/massive-waste-reduction-for-westfield-due-to-rendisk http://www.rendisk.com/solutions/food-waste-solutions/flex-wastedispo-dehydrated http://www.rendisk.com/application/files/5314/8161/9798/Brochure_Rendisk_Flex_WasteDispo_2016_DEF.pdf http://www.publicityworks.biz/2016/09/westfield-london-puts-sustainability-in-the-scullery/
NR9	Commercial precinct	FW (part)		Dehydrator & waste to water ORCA		**PRECINCT FOOD COLLECTION & TREATMENT** There are well of 50 Hungry Giant dehydrators in Sydney such as the Darling Quarter, Commonwealth Bank Building and Retail Precinct, HSBC Building with 23 restaurants and nine coffee shops, State Theatre, Hurstville Central Shopping Centre, and Australia Square. In Melbourne, Degraves is a busy café with a high density of food businesses and over 100,000 people passing through per day. Recycling of multiple waste streams was set up in 2013 by the city council (the Degraves Street Recycling Facility) due to low recycling rates, poorly managed bins and significant opportunity the site provided. Food waste (approx. 700 kg/day according to 2012 audit) was transported from approx. 30 cafes by a team of recyclers collecting various types of materials. The team worked with the cafés and restaurants on education of kitchen separation and transfer of waste to the on-site waste recycling facility in which a dehydrator was located. The food waste was shredded, heated and dehydrated with the Gaia dehydrator machine. The soil conditioner produced was supplied to local community gardens and council parks and gardens. The aim of the project being to achieve a 70% reduction in the volume of food waste collected from participants. From an evaluation conducted in 2015 (Mitchelmore 2015) on two years of operation a reduction of 69% was achieved despite the dehydrator being out of commission for 4 months before repair. Since 2017 the system, located within an underground parking lot, has been modified with now over 100 cafes in the area using a new ORCA waste-to-water system which discharges processed food waste to sewer for further regional treatment by AD. The original dehydrator, with 600kg capacity/day, now being used mainly to treat coffee grounds. The service is free to all traders with three to four full time equivalent staff managing the full recycling facility and with two adjacent recycling hubs encouraging residents to participate. The electric vehicles used to collect all recycling materials providing pick-up facilities up to 8 times a day.	https://ssroc.nsw.gov.au/wp-content/uploads/2018/12/10_RFB-Fact-Sheet_Food-Organics-Dehydrators_final-1.pdf Degraves Systems supplied by EcoGuardians Australia (http://www.ecoguardians.com.au/products/gaia-recycle Originally in 2013 a dehydrator was used to process food waste (https://www.mwrrg.vic.gov.au/assets/resource-files/Degraves-Street-Recycling-MF-R1-Final-Report-Melbourne.pdf) + (http://www.cultivatingcommunity.org.au/wp-content/uploads/2018/01/Exploring-In-Vessel-Food-Waste-Processing-Units_update2018.pdf) Since 2017 - ORCA http://wastemanagementreview.com.au/tag/orca/ and the original dehydrator to treat coffee grounds (https://www.feedtheorca.com/war-on-waste-degraves-street-recycling-facility-uses-orca/) figs/details (https://sustainability.ceres.org.au/our-say-waste-not-want-not/), https://www.mwrrg.vic.gov.au/assets/resource-files/Metro-Fund-Melbourne-Degraves-Street.pdf
NR10	Commercial – office, catering and café food waste	FW	Cargo bikes, caddies	Micro AD > digestate		**LOCAL-SCALE AD** In 2012/13, the Local Energy Adventure Partnership (LEAP) conducted feasibility studies into the creation of a micro-AD network in the London Borough of Camden and specific potential sites. Three pilot plants were established to test different equipment configurations and end uses of biogas and digestate. The first plant is in Camley St Nature Park, overlooking a canal. A cargo bike is used to collect catering and office food waste within a mile radius. Biogas is used for cooking on site by a community café which also feeds the AD plant. The digestate is used on a local railway embankment to grow food supplied back to the café. The second plant at the Calthorpe Project, a community centre and garden, also has a café feeding the digestor with food waste while biogas produced is used on site for cooking and heating. In colder weather a polytunnel is used to extend the growing season and experimentation on digestate as a soil medium for limited urban spaces. The third plant is in East London and part of R-urban, an EU funded collaboration project involving public works, an architect and artists. The AD plant, housed within a shipping container, was assembled through a series of knowledge sharing workshops. The site, located on a social housing estate, part of a community reuse resource with a café. The Camley St site, treating 24kg of food waste a day, was used for the subject of an academic review in 2014 (Walker et al 2017; Theaker et al 2017).	Urban micro AD, UK https://www.researchgate.net/publication/313411207_Assessment_of_micro-scale_anaerobic_digestion_for_management_of_urban_organic_waste_A_case_study_in_London_UK https://fstjournal.org/features/31-3/micro-scale-ad http://communitybydesign.co.uk/pages/our-pilot-system
NR11	Commercial AD	FW (most) FOG?	80L bins	AD		**COMMERCIAL PRECINCT-SCALE ON-SITE AD** Federation Square is a government building in the heart of Melbourne with multiple sustainability features and objectives. From 2014 to 2017 up to 800 kg of food waste from on-site cafes and restaurants was delivered to a busy loading bay in the basement of the complex in 80 L bins where the on-site AD plant run by Active Research was located. Material was macerated and pumped into the AD plant, which produced biogas (up to 14,400 L/day) used to heat water by a boiler in the building. Biosolids were collected and used by the AD manufacturer staff for garden compost. Excess water was disposed to sewer in accordance with the trade waste agreement. The plant operated successfully for three years (2014-2017) but due to ongoing maintenance callouts due to contaminants such as cutlery entering the system the plant was finally decommissioned in 2017.	http://www.activeresearch.com.au https://home.kpmg/au/en/home/about/clients/active-research.html Victorian food organics recycling -A guide for small-medium food services organisations https://www2.health.vic.gov.au/about/publications/policiesandguidelines/victorian-food-organics-recycling-guide

NO.	SECTOR	STREAMS	COLLECTION TRANSPORT	TREATMENT/ OUTPUT	IMAGES	DESCRIPTION	REFS
NR12	Commercial CE hub	FW (most)		CE, aspiration AD		**CIRCULAR ECONOMY BUSINESS PRECINCT HUB** The Plant a former meat packaging plant was repurposed in 2011. Housing a collection of synergistic businesses (brewery, bakery, aquaponic farm, mushroom farm, kombucha supplier, two veg suppliers etc.) it acted as a food business incubator and vertical farm. The facility being not only a building but a business community, a living lab, home to farmers markets and an educational showcase for over a 1,000 tourists every month. The Plant, taking the waste from one small business (i.e. the brewery in the form of spent barley) using it to feed another business (i.e. the fish farm). The intent was to use final waste products for use in an on-site AD plant with the biogas produced used to run a turbine to create energy and light to grow plants to help close the loop for other businesses. The Plant's aspiration was to eventually treat waste on-site and import further food waste from nearby businesses to feed the AD plant and power the Plant as well as adjacent homes. Having run for over eight years the Plant businesses were moved in 2019, with only the markets remaining. Status of the Plant #2 location is currently unknown.	https://www.bubblydynamics.com/the-plant https://plantchicago.org/2019/09/26/were-moving/ https://energyedger.com/tag/anaerobic-digester/ https://www.nytimes.com/2019/09/21/climate/circular-food-economy-sustainable.html
	REGION/CITY-SCALE						
NR13	Supermarkets Banning food waste to landfill			> food redistribution		**GROCERY STORE FOOD WASTE BAN (COUNTRY-SCALE)** In 2016 France became the first country in the world to ban supermarkets from disposing unused food to landfill, 11% of the country's food waste. Supermarkets of a certain size must donate unused food or face a fine. Other policies require schools to teach students about food sustainability, companies to report food waste statistics in environmental reports, and restaurants to make take-out bags available.	https://www.csmonitor.com/Environment/2018/0103/How-France-became-a-global-leader-in-curbing-food-waste
NR14	Commercial Regulation banning organic waste to landfill			Composting or AD		**MANDATORY COMMERCIAL ORGANICS RECYCLING (STATE-SCALE)** In 2014 the Governor of California signed a Bill, the Mandatory Commercial Organics Recycling (MORe) program, requiring all commercial generators of organic waste to have their food waste, landscape/green waste, food-spoiled paper and non-hazardous wood waste either composted or sent to AD to assist in increasing diversion and preserving landfill capacity. The program allows for staggered commencement dates. Similar programs have been implemented in Connecticut, Massachusetts, New York City and Rhode Island to varying degrees.	https://ilsr.org/rule/food-scrap-ban/california-organics-recycling/ https://ilsr.org/rule/food-scrap-ban/
NR15	FW collection	FW (most) FOG	Trucks	AD (EarthPower) > biogas & digestate (pellets)		**REGIONAL-SCALE AD** EarthPower, a privately-operated AD plant in western Sydney, was acquired in a joint venture by Veolia and Cleanaway in 2007, the first regional FW-to-energy facility in Australia. With a capacity of 52,000 t/a it converts domestic, commercial and industrial food and liquid organic waste including FOG into biogas used in cogeneration engines to produce green energy (enough for 3,600 homes) and sludge/digestate which is dried and granulated into fertiliser pellets and sold to the agricultural and horticultural markets. The fertiliser pellets being transported to a number of potential destinations depending on demand including Western Australia. Waste heat from the cogeneration engines is used in the sludge drying process and to heat the digestors.	https://earthpower.com.au/about-us/ Lewis et al 2017
NR16	FW collection	FW (most) FOG?		WWTP AD		**WASTEWATER TREATMENT PLANT COGENERATION** In early 2016 Sydney Water commenced a 3-year project co-funded with the NSW Government aiming to lower energy costs and customers' bills. By building another tank to take liquefied food waste Sydney Water is able to augment its existing AD plant processing sewage sludge and a co-generator engine generating power at the Cronulla WWTP. The food waste helps to boost the microbes creating methane and generate additional power required for operations at the Cronulla plant. SWC has partnered with Pulpmaster to bring the liquefied food waste from its clients to the Cronulla WWTP. Pulpmaster supplies equipment to commercial kitchens and markets to turn food waste into a slurry. The food waste for the Cronulla WWTP originally aiming to collect the food waste from five commercial businesses. The project not only diverts food waste from landfill (estimated at 150,000 wheelie bins) but has the potential to generate more than 60% of the energy the plant needs to operate, which is equivalent to powering a third of homes in the Cronulla area per year. In Melbourne a ppurpose built waste to energy plant located adjacent to the Aurora wastewater treatment plant is expected to divert 33,000 tons of commercial food waste per year from 2017. The biogas produced will power both the existing wastewater treatment plant and AD food waste processing plant. Surplus energy generated will be exported to the electricity grid.	http://wastemanagementreview.com.au/utility-first-food-waste-to-energy-plant/ http://www.abc.net.au/news/2016-05-30/food-waste-powering-sydney-water-sewage-plant/7460182 https://www.yvw.com.au/about-us/news-room/turning-organic-waste-energy https://www.yvw.com.au/about-us/news-room/two-years-yarra-valley-waters-waste-energy-plant-still-game-changer https://www.wsaa.asn.au/sites/default/files/publication/download/Case%20study%2010%20Aurora%20food%20to%20waste%20energy%20plant.pdf
NR17	FW collection CE hub	FW		WWTP AD > CE		**CIRCULAR ECONOMY WASTEWATER TREATMENT HUBS** In 2013 the Zemka biogas plant in Austria is an example of utilising multiple organic waste streams (biowaste, food waste, sewage sludge, liquid waste FOG) to produce biogas and heat for a local spa. The biogas plant combining high substrate flexibility with intelligent biogas valorisation was constructed on an old MBT plant site for bio-waste and municipal solid waste (MSW). To guarantee maximum flexibility, different reception and pre-treatment lines were designed, with the streams containing impurities needing treatment before the wet AD step. For the valorisation concept two paths had to be considered, conversion to heat for the thermal bath Tauern SPA (more than 2km distance) and the upgrade of the surplus biogas. Biogas is purified by external biological desulphurization with oxygen dosing and a three-step condensation cooling gas to -50 C. Despite raw material composition fluctuating weekly as well as seasonally the production of CH4 is stable. There are many other AD plants using multiple organic waste streams such as food waste, sludge, liquid waste and FOG based on circular economy principles emerging around the world. With the organics being used for a variety of outputs such as biogas to convert to green energy for local houses, heat, fertilizer. More advanced CE hubs are producing/aiming to produce CO2 for algae production, bioplastics and proteins, specific nutrient extraction (i.e. Billund biorefinery in Denmark and Buiksloterham, Amsterdam, The Netherlands – both established 2013/14).	Jazbec and Turner 2018 https://www.researchgate.net/publication/330900213_Creating_a_circular_economy_precinct
NON-RESIDENTIAL (INSTITUTIONAL)							
NR18	Schools	FW & GO	Caddies/bins	Composting and worm farming		**SCHOOL COMPOSTING** Dulwich Hill Public School within the Inner West Council area established their veggie garden and frog pond over a decade ago. They now also have a native garden (and supermarket) together with an extensive set of compost bins, worm farms and mulch stations. The school has a roaster for gardening activities and the collection of food scraps from class rooms for composting/worm farm treatment. Due to the educational component of having a garden, composting and worm farm on-site at school students make connections to activities at home.	https://www.epa.nsw.gov.au/news/news/2019/conversations-article-from-little-things-big-things-grow

NO.	SECTOR	STREAMS	COLLECTION TRANSPORT	TREATMENT/ OUTPUT	IMAGES	DESCRIPTION	REFS
NR19	Commercial markets	FW (part)		Various Worm farms, compost, biofuel		**MARKET FOOD WASTE TREATMENT** In 2014 the Queen Victoria Market in Melbourne installed 5 worm farm bins. Each can take up to 2 kg of waste such as coffee grinds, chai leaves and fruit and veg. The fertiliser produced is reused on potted trees and plants around the market. The worm farms are strategically placed for educational purposes. Since 2016 Assetlink Services have been contracted for cleaning and waste management. The fruit and veg from stallholders is being segregated and bulk hauled to an open wind composting facility. Initially recycling dealing with 120 tonnes/month. Other organics recycled at the market include: fat and bone which is used in blood and bone fertilizer; fish offal which is collected and processed for stockfeed and fertilizer; FOG from grease traps and UCO processed into stockfeed or converted to biodiesel at various processing facilities.	Melbourne Vic Markets https://qvm.com.au/sustainability/recycling-program/
NR20	Park pet waste	PW	Degradable bags	On-site compost		**DOG PARK ON-SITE COMPOSTING** In 2014 it was estimated that 4% of the municipal waste passing to landfill in San Francisco was dog waste in bags, the same % as diapers. In 2016 managers of the East River State Park (ERSP) set up an on-site dog waste composting facility, inspired by the Notre Dame de Grace Park in Montreal, Canada (2005 – 2010) where in 4 years the managers collected nearly 1,500 tons of dog waste. As the bins fill the waste is dumped into a "Nitrogen Supply Bin," where it is mixed with sawdust. When that bin is full, it is transferred into the "Cooking Bin," where it is heated and mixed for the next 6-8 weeks, and then moved to the "Curing Bin." It stays there for a year, after which it is ready for use on the gardens. In 2019, inspired by ERSP, Battery Park City will run a year long trial at three of its parks (the North End Avenue Island, 'Sirius' at Kowsky Plaza, and at the south end of West Thames Park). The pilot will collect dog waste from the three parks and treat it at a central composting facility along with other organics such as food waste and wood chips from residential and non-residential properties. In 2018 the authority treated over 9,000 kg of dog waste.	https://www.latimes.com/nation/la-oe-lewis-dogs-environmentalism-20141102-story.html East River State Park, NY, USA https://www.humanimpactsinstitute.org/single-post/2016/07/19/Dog-Waste-Only Battery Park City https://patch.com/new-york/downtown-nyc/dog-poo-compost-plan-combats-climate-change-battery-park-city Paper on Montreal. https://www.tandfonline.com/doi/abs/10.1080/1065657X.2007.10702339
NR21	Park pet waste	PW	Degradable bags	AD On-site Light demo		**DOG PARK ON-SITE AD** The first Park Spark was installed in Tudor St, Cambridge, Massachusetts in 2009/10. Funded by MIT in collaboration with the City of Cambridge, the concept involves dog owners using biodegradable bags when they pick up after their dogs in the park. They put the bag full of dog waste into the receiver and turn a wheel which mixes the dog waste and water in a small AD plant. This produces biogas which is used to power a street lamp as a form of education/art. There are similar projects in the UK.	Park Spark Project, Cambridge, Massachusetts, USA http://parksparkproject.com/artwork/1687212.html https://www.wired.com/2010/09/dog-poop-powers-park-lights/
NR22	Aquatic centres	Wood chips				**AQUATIC CENTRE HEATING** At the end of 2018 the City of Albany in WA switched over the heating of its Leisure and Aquatic Centre to a biofuel system after 5 years of planning, aiming to reduce its reliance on gas and save $50k a year. Similar to the Mt Gambia Aquatic Centre in South Australia it runs on woodchips, which are to some extent contested as sustainable. Whilst examples of the use of AD for pool heating are difficult to find there is literature highlighting the potential.	https://www.abc.net.au/news/2018-12-12/woodchip-heater-warms-local-swimming-pool/10595978 http://www.renewablessa.sa.gov.au/content/uploads/2018/01/160625-aaron-izzard-cmg-aquatic-centre-biomass-boiler.pdf https://www.ieabioenergy.com/wp-content/uploads/2011/10/Update_Energy_crop_2011.pdf
NR23	University/ commercial					**UNIVERSITY FOOD WASTE DEHYDRATORS** Since 2015 food waste has been separated at UTS in preparation for ClosedLoop dehydrators installed in 2016/17 to assist in reducing waste to landfill across the campus. Food waste is now collected from 22 staff/student kitchens, public waste bins servicing 34,500 students and staff, 11 individual cafes and a food concourse area servicing 5 food outlets. The food waste is collected daily via dedicated 120 L bins by cleaning staff, transported and weighed before being loaded to two industrial scale rapid food decomposer/dehydrator systems in the car park basements of two separate UTS buildings. The dehydrated material is currently transported to EarthPower to generate green energy and soil conditioning material. The units have the capacity to convert 50 to 60 t/a of organics (producing 5 – 6 t of soil conditioner). Although currently sent to EarthPower UTS aims to work with stakeholders to use the material for application to land in accordance with NSW EPA waste regulation. The project is not only providing sustainability benefits but is being used by students as a case study in a UTS design course. Since 2019 a trial has been in place taking the dehydrated material to a garlic farm west of the Blue Mountains, which also receives coffee grounds and other food waste from near UTS. The garlic grown brought back to the contributing cafes to help test circular economy principles.	https://closedloop.com.au https://www.uts.edu.au/research-and-teaching/our-research/institute-sustainable-futures/our-research/foodfutures/food
NR24	Institutional	FW	Caddy>bin	AD		**UNIVERSITY FOOD WASTE GRINDER COLLECTION SYSTEM** Western Sydney University was the first university in Australia to trial Pulpmaster. Since 2011 food waste from the university cooking classes has been taken in small labelled bins from each cooking station after the classes to the Pulpmaster unit adjacent to the kitchens by technical staff. The Pulpmaster unit macerates the food waste into a slurry before it is pumped to a holding tank outside the building. This is then taken by a Pulpmaster tanker on a regular basis to EarthPower at Camelia in Western Sydney where it is processed into green energy and soil conditioning material. From 2011 to 2014 52 tonnes of food waste was recycled.	https://pulpmaster.com.au https://www.youtube.com/watch?v=M9nDOZQcsSA http://www.thefifthestate.com.au/education/university-sustainability-research-the-latest-update/60491
NR25	Inst	FW	Macerator sink	AD (simple) Liquid fertilisers And inoculated composting	 	**UNIVERSITY ON-SITE TREATMENT** James Cook University (JCU) produces over 50 t of food waste every year. In 2013 JCU began to use the Bio-Regen process (by VRM-BioLogik), where JCU's residential college commercial kitchens feed food scraps to an in-sink macerator. The resulting slurry mixed with water at a ratio of 1:2 is inoculated with Bokashi microbes and allowed to ferment in tanks for a month. The end product is then used at JCU seedling farms or sold to farmers as a liquid fertiliser boosting carbon, nutrient and water retention levels of soils, typically being mixed with sand at a ratio of 1:10. Early in the testing it was discovered that due to the large volumes of food waste and particular types (i.e. avocado seeds, bones, bulky items) a complementary process, Groundswell, was needed. This process also on site uses an inoculated composting process.	James Cook Uni (Bio-regen pilot started in 2013 http://www.cultivatingcommunity.org.au/wp-content/uploads/2018/01/Exploring-In-Vessel-Food-Waste-Processing-Units_update2018.pdf https://www.jcu.edu.au/tropeco-sustainability-in-action/sustainable-campuses/recycling-and-waste/food-waste-the-bio-regen-unit https://www.sbs.com.au/food/article/2018/10/02/aussie-uni-turning-food-waste-fertiliser http://www.vrm.science/docs/default-source/default-document-library/pilot-project_vrm-biologik.pdf?sfvrsn=fb8f67b2_2
NR26	Hospital	FW	Vacuum, macerated	Compost		**HOSPITAL FOOD WASTE VACUUM & GRINDER COLLECITON SYSTEM** As South Australia's largest teaching hospital the Royal Adelaide Hospital has 650 patient beds, employs 4,100 full-time and casual staff and has over 300 residential students. Each year the hospital caters for 50,000 emergencies and 400,000 outpatients. The main kitchen provides 2,000 meals a day plus another 820 for associated facilities. In 2009 the hospital invested in a vacuum system for the main kitchen as part of the new integrated environmental management plan and aim to reduce waste across the hospital. Three collection stations in the food preparation and dishwashing areas receive the food waste which is then transferred to a grinding machine. A small amount of water is added and the liquefied food waste transferred to a 7,000 L tank for collection 1 to 2 times a week. A garden supply company turns the material into compost for resale. Currently 218 tonnes of kitchen food waste is recycled annually.	Problem with Zerowaste SA pdf. ref http://www.zerowaste.sa.gov.au/upload/REAP/91392%20ZWSA%20UpClose%20RAH%20WEB.pdf https://wealthfromwaste.wordpress.com/tag/royal-adelaide-hospital/