Industry 4.0 for energy productivity: insights and future perspective for Australia

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Abstract: This study aims to explore various domains within Industry 4.0 (I4.0) and energy productivity in Australian context. In doing this, the study analyses I4.0 technologies & services, barriers to I4.0 for energy productivity, regulatory framework, multiple benefits of I4.0 technologies, relevant business models, and roadmap to I4.0. The findings show that inadequate IT infrastructure, cyber security, complex supply chain and contracting, uncertainty about return on investment (RoI) are significant barriers. When it comes to productivity benefits, this study has highlighted macroeconomic impact, industrial sector impact, public budget impact, health and well-being impact, and energy delivery impact stemming from I4.0 technologies. In terms of regulatory framework, this study finds that given the near-ubiquitous data generation and use across the digital economy, it is quite difficult to exhaustively address all legal and regulatory issues relating to I4.0 technologies in the energy sector. However, there are several business models (e.g. X-as-a-service or pay per X) which can be applied to adopt I4.0 technologies. The study concludes with a roadmap to I4.0 with future research directions.

Keywords: Energy productivity, industry 4.0, manufacturing, Australia.

1 Introduction

Energy sustainability is arguably among the most pressing socio-environmental concerns of modern times. In Australia, the major portion of the energy comes from fossil fuel which leads to very high anthropogenic carbon emission. The Australian energy sector must transition so that it can provide consumers with reliable affordability and clean energy into the future. The Australian government has set a target to increase energy productivity by 40% within 2030 [1].

International Energy Agency (IEA) found that digitalization in energy could cut energy use by about 10% by using real-time data to improve operational efficiency and system flexibility [2]. Thus, the sustainable energy transition and I4.0 share important characteristics that can be interconnected to attain both economic benefit and socio-environmental benefit.

This study aims to present the major findings of a research project sponsored by "RACE for 2030 Cooperative Research Centre" for energy and carbon transition in Australia [3]. The aim of RACE for 2030 is to drive energy innovation across the supply chain to deliver improved, lower cost and lower emission energy services. Five research themes are mainly highlighted in RACE for 2030, which are I4.0 technologies for energy productivity, decarbonization of industrial process, energy productivity in value chain, demand control, and anaerobic digestion for utilities. However, this study outlines the major services and benefits that I4.0 technologies offer, together with the analysis of the most relevant barriers, major regulatory issues, and emerging business models following with the research roadmap outlining prioritized potential research initiatives. Fig. 1 shows the approach that we have taken in this study. The research roadmap is built upon four main pillars. For each of the pillars the approach has been started of doing the literature review and the interview with focus groups and policy experts to understand the relevant issues in Australia. The study represents a first-of-a-kind attempt to assess the major elements for improving energy productivity in Australia in businesses based on the adoption of I4.0 solutions. The study would help the industrial decision makers and policymakers to adopt I4.0 technologies in their organizations, in particular tackling barriers, finding suitable business model, setting the regulatory framework as well as shaping the strategy towards I4.0.

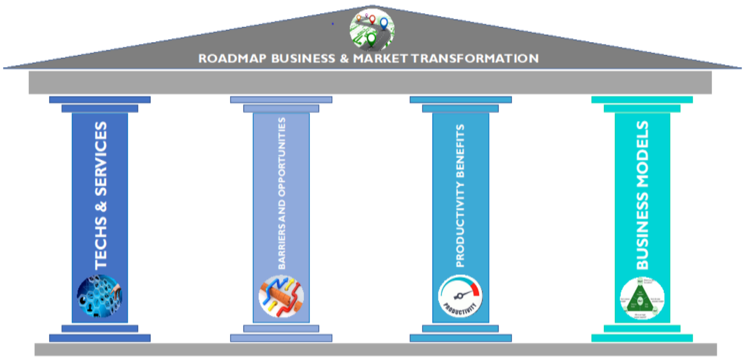

Fig. 1. Approach taken in the study

2 Industry 4.0 technologies and services

The International Energy Agency (IEA) explained the concept of I4.0 as "*the increasing interaction and convergence between the digital and physical worlds*", where the digital world has three fundamental elements which are data, analytics, and connectivity [2]. Cyber physical system, Internet of Things (IoT), additive manufacturing, automation, cloud technologies, visualization technologies, Artificial intelligence, and big data are the core part I4.0. The set of I4.0 technology offers several services which are not limited to energy efficiency, real time monitoring, resource management, interoperability, autonomization, and flexibility.

3 Barriers to Industry 4.0 for energy productivity

In this study, barriers are categorized into technological, economical, regulatory, and social. The specific barriers within each category are ranked based on the feedback of focus group. In all focus groups, a series of questions were administered using “Slido” live polls. In addition, qualitative responses were elicited from focus group participants with regards to specific questions. The responses to the “Slido” polls are presented in Fig. 2.

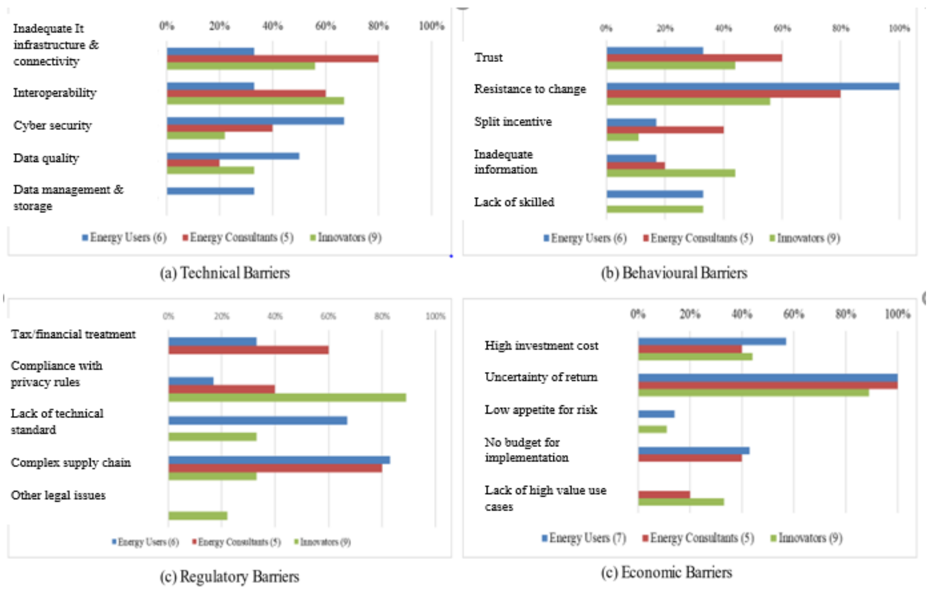

Fig. 2. Barriers to I4.0 for energy productivity

In Fig. 2, the greatest disparities between the groups were in the higher importance attached by the energy users to cyber-security and data quality as technical barriers to adoption, while the energy consultants’ group saw inadequate IT infrastructure and connectivity as the largest barrier. While all groups saw the greatest behavioral (or social) barrier as being resistance to change or new processes, with a lack of trust also being regarded as important, the energy users and innovators were more concerned than the energy consultants about the lack of skilled workforce. On the other hand, the greatest regulatory barrier perceived by energy users and consultants was the complex supply chain and contracting. Innovators were most concerned with privacy rules and more broadly, access to data that may be controlled by other service providers – which could also be seen as complexity in contracting. Furthermore, all groups agreed that the most important economic barrier was the uncertainty about the return on investment (ROI) from I4.0 technologies, which often also applies to energy productivity investments, with the high cost of introducing new technologies of particular additional concern to energy users. This reflects a common Australian business concern about up-front costs, also reflected in a focus on short payback periods for energy productivity investments.

4 Productivity benefits from Industry 4.0

Certain technologies identified as 'energy-efficient' because of their positive impact on energy reduction, will also bring several additional benefits (e.g., production yield improvement, reduced maintenance cost) to the production or business process [4], [5]. These additional benefits are collectively referred to as 'productivity benefits', 'multiple benefits' or 'non-energy benefits' (or NEBS), because in addition to reducing energy consumption and/or costs, they all increase the productivity of the firm [6].

The applications of I4.0 technologies simultaneously manifest in various sectors and across multiple levels [7]. However, taking inspiration from the previous literature [8], the study has considered five different dimensions to assess the impact level of energy-efficient technologies stemming from I4.0, which are macroeconomic impact, industrial sector impact, public budget impact, health and well-being impact, and energy delivery impact. Multiple benefits stemming from I4.0 technologies are presented in Fig. 3.

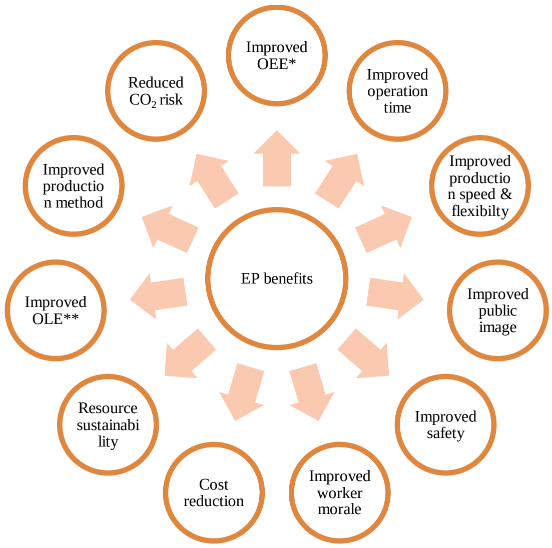

Fig. 3. Multiple benefits associated with energy productivity measures [8]. Note: * OEE is Overall Equipment Effectiveness and **OLE is Overall Labor Effectiveness

5 Regulatory framework for Industry 4.0

I4.0 technologies incorporate the collection, processing and use of data at large scale. Therefore, there needs to have an emphasis on the main framework for regulating large-scale data collection, processing, analysis and use under Australian law. However, given the near-ubiquitous data generation and use across the digital economy, it is impossible to exhaustively address all legal and regulatory issues relating to I4.0 technologies in the energy sector.

Large-scale data practices – including the collection, analysis and use of data – form the core of I4.0 technologies. Given that these technologies and business practices are both recent and continuously evolving, it is unsurprising that there is an ongoing need for legal and regulatory frameworks to adjust. Consequently, there are completely new regulatory regimes – such as the Consumer Data Right (CDR) and critical infrastructure regimes – that have been specifically developed to achieve policy objectives, such as promoting data use and sharing, and securing data. Moreover, existing legal regimes, such as data privacy laws, are being challenged by evolving data practices, contributing to current proposals for fundamental law reforms. In addition, there is increased use of less formal (and more flexible) rules, often known as 'soft law', such as voluntary codes and standards.

6 Business models for Industry 4.0 energy productivity

The business models are all designed to leverage the mass of data that stems from the adoption of I4.0 technologies and multiple data streams from other sources that support data analytics– from the digital design of a product, through digital monitoring and control of production, to digitally enabled after sales service, maintenance and finally disposal or recycling. This so-called "digital thread" acts as an enabler for improved communication, monitoring, understanding and ultimately decision-making. However, it is also important to note that business model patterns such as these are rarely found in isolation, typically there are multiple patterns being leveraged within a single business model e.g., the X-as-a-service [9] and pay-per-X business models [10].

In addition, whilst these business models hold great market potential, some are yet to secure a strong foothold in extant markets. The flexibility of the servitization approach, for example, has often been met with challenges in terms of the ambiguity customers may experience whilst trying to decipher the value proposition of some service offerings, as Langley [11] mentions "many new servitization solutions result in a worse customer experience as new ways of working have not yet been optimally designed". This, combined with the operational and managerial nuances associated with the shift to a servitization strategy result in the persistence of considerable barriers to uptake, particularly in the case of manufacturing organizations and the steel industry. Along the collaborative front, when it comes to the necessity for collaborative activities in leveraging I4.0 enabled business models, such activities, and the formation of collaborative networks in particular, are still being treated as a burden on organizations. Other challenges to the implementation of I4.0 enabled technologies include the likes of conflicting business models with traditional modes of operation, potential for significant impact on entire value chains, impact on prices and regulatory concerns as well as the intellectual property rights and patent considerations stemming from the democratization of production that may be a core existing activity [12].

Nonetheless, the opportunities associated with their adoption hold the potential to also be of significant benefit for participating stakeholders. Digital platforms, for instance, are already well-established in many industrial contexts and are a pillar of effective I4.0 application. Blockchain (and other similar emerging models), has opened up the potential for greater transparency in supply chains, decreased operational costs and the provision of better monitoring and performance control. It also facilitates trust and financial transactions that reflect value identified through data analytics and other I4.0 mechanisms. These complement developments of "Circular Economy" business models as well as increasing focus on addressing Scope 3 carbon emission due to activities of agents upstream and downstream from an individual business.

7 Roadmap to Industry 4.0 for energy productivity in Australia

A critical success factor for the adoption of I4.0 solutions for energy productivity is the cooperation between stakeholders operating in the energy efficiency market. Indeed, investors, utilities, governmental agencies, financial institutions, local authorities, research and development organizations, equipment manufacturers, market institutions, Energy Service Companies (ESCOs), and international institutions can all play vital roles. It is thus important to try enlarging as much as possible the perspective, identifying which stakeholders may be in the best position to develop and stimulate the most effective drivers to promote I4.0 solutions for energy productivity. In fact, to draw the roadmap towards I4.0, it is necessary to reframe what is possible to open new possibilities. Moreover, raising the priority level of I4.0 is also crucial along with shifting the balance for the decision makers to capture the benefits of I4.0.

IEA has suggested several strategies for digital energy efficiency deployment [13]. By taking inspiration from IEA, this study has emphasized six strategic focus areas which are (i) cybersecurity frameworks and guidelines, (ii) methodologies for valorizing energy efficiency/productivity, (iii) removal of interoperability barriers, (iv) stakeholders' awareness and capacity building, (v) institutional arrangements and platform for data sharing and data management, and (vi) pilot projects. In fact, eleven research projects (e.g., "I4.0 energy productivity networks – sharing knowledge to improve competitiveness", "smart metering and Artificial Intelligence for industry decarbonization") are proposed for future roadmap covering the focus areas (see Fig. 4). Each of the focus areas serves the CRC RACE for 2030's work of creating the ground for and accelerating the deployment of I4.0 solutions for energy productivity in industry and non-residential buildings, for transformative performance, energy productivity, and sustainability of all Australian businesses.

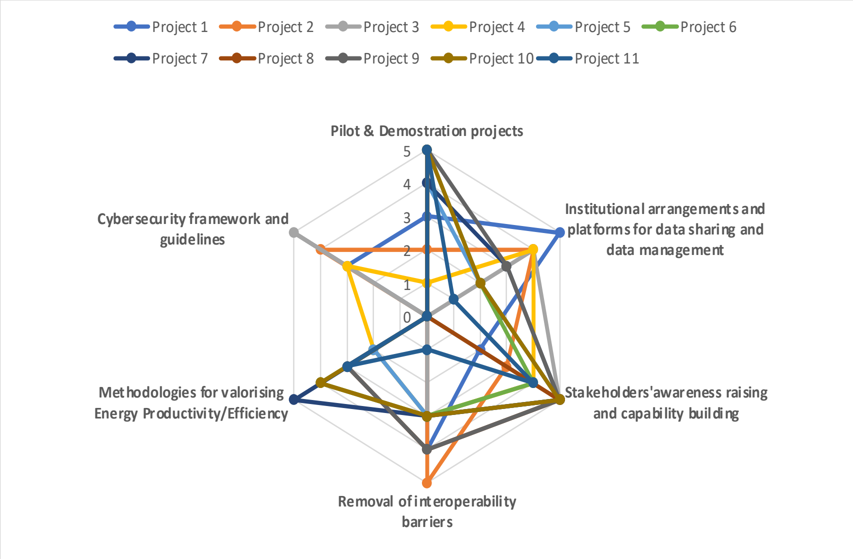

Fig. 4. Proposed projects covering the focus areas of IEA

8 Conclusion discussion and future research perspective

The present study discusses the barriers, regulatory models, business models, productivity benefits, and roadmap to I4.0 for energy productivity in Australia. In fact, the findings of this study are very crucial to shape the future roadmap of I4.0 in Australia. In addition, while the specific goals and policies of this study might be different, the concepts and approaches used in this research can certainly serve as an inspiration and guidance for other countries looking to address similar challenges and transition to I4.0 for energy productivity.

The future work around energy productivity and I4.0 will be about motivating the integration of use cases and functions relating to energy productivity within already digitally transformed (or transforming) business and sites. However, much more often in the present Australian context future work by RACE for 2030 in harmony with others will have to simultaneously promote energy productivity via I4.0 and the actual adoption of I4.0 in a broader sense. That is, energy productivity and I4.0 adoption are interdependent, with I4.0 being the broader issue, as it impacts on broader aspects of business value and productivity than does energy productivity. RACE for 2030 efforts to encourage energy productivity improvement must fit within this broader I4.0 context and will need to dovetail with the already-extensive public and private sector activity that seeks to move businesses up the I4.0 staircase.

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