Title: Enhancing ecosystem services through targeted bioenergy support policies

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Abstract

While policy-makers in the bioenergy sector have paid considerable attention over the past decade to the risks that energy cropping can pose to forests, soils and food security, there has been less focus on how bioenergy policies can be designed to enhance ecosystem services. Some perennial energy crops have demonstrated the potential to provide habitat for biodiversity, improve soil health, enhance water quality, mitigate dryland salinity and sequester carbon. While much uncertainty exists around which forms of energy cropping might deliver these benefits, opportunities exist to preferentially support beneficial energy crops through the adaptation of existing bioenergy policies. This article provides a global review of bioenergy policy instruments that identifies existing and potential mechanisms for promoting the enhancement of ecosystem services. While many existing bioenergy support policies promote fuel supply (a provisioning service) and climate change mitigation (a regulating service), it is less common for bioenergy policies to actively enhance ecosystem services such as habitat provision, soil improvement and water regulation. Further opportunities to promote these ecosystem services exist through structured tax concessions, sub-mandates, banding and renewable energy auctions, but careful consideration needs to be given to trade-offs between services, risks of disservices and the need for complementary non-energy policies.

Highlights (3-5 bullet points)

- Some energy cropping systems have shown potential to enhance ecosystem services
- Restoration of degraded land is a goal of the EU Renewable Energy Directive
- Further opportunities involve tax concessions, auctions, banding and sub-mandates
- Complementary policies are required to guard against threats

Keywords (max 6)

Energy crop; ecosystem services; bioenergy; restoration; complex systems; market-based instruments

1. Introduction

Bioenergy support policies have attracted criticism due to their potential to diminish ecosystem services, for example by incentivizing the clearing of biodiverse tropical forests to make way for oil palm plantations in Southeast Asia (e.g. Boucher et al., 2011; Gao et al., 2011; Gerasimchuk and Koh, 2013). However, energy cropping systems also have the potential to enhance ecosystem services, such as providing habitat for biodiversity, reducing soil erosion, enhancing water quality, mitigating dryland salinity and building soil carbon (Holland et al., 2015; Lowrance and Davis, 2014; Maletta and Lasorella, 2014; Simpson et al., 2009).

Berndes and Fritsche (2016) argue that many discussions of bioenergy policy tend to assume that any land use change for bioenergy is inherently "bad" and ignore the possibility that sustainable bioenergy production may be preferable to many current land uses that are unsustainable. Bioenergy production is not the only commercial land use activity that has this potential to enhance biodiversity, reduce soil loss and mitigate climate change, with other land uses such as agroforestry also capable of providing similar benefits (Stanturf, 2015). However, the bioenergy sector presents unique opportunities for innovative policy development around ecosystem service enhancement for three main reasons:

1. The diversity of bioenergy support measures that have been adopted around the world and the high degree of policy experimentation that has taken place.

A wide range of policy instruments are used across the world to promote bioenergy, including transport fuel mandates, electric utility quota obligations, feed-in tariffs, subsidies and tax breaks (REN21, 2016). The primary aims behind many of these policies have been climate change mitigation through the replacement of fossil fuels (e.g. EU Renewable Energy Directive) or enhanced energy security (e.g. US Renewable Fuel Standard). However, the knowledge gained through this policy experimentation also has the potential to be applied to the promotion of energy cropping systems that enhance ecosystem services.

2. The relative lack of attention paid to the enhancement of ecosystem services through bioenergy policies and decision-support tools.

The attention paid to the enhancement of ecosystem services by bioenergy policy-makers has been relatively low compared with the attention paid to preventing negative impacts over the past decade (e.g. incorporating sustainability criteria into bioenergy policies under the EU's Renewable Energy Directive). Similarly, the attention paid to enhancement of ecosystem services in the bioenergy sector has been low relative to other sectors. For example, a recent review by Grêt-Regamey et al. (in press) identified multiple decision-support tools to operationalize the ecosystem services in sectors such as forestry and spatial planning, but could not find any tools that had been developed specifically for the bioenergy sector.

3. The energy cropping sector is undergoing a period of transformation, particularly in relation to the shift from first-generation to second-generation (or advanced) biofuels.

Key jurisdictions for bioenergy production and consumption, such as the EU and the USA, have been actively promoting a shift away from first-generation biofuel crops such as corn, sugarcane and oilseeds towards cellulosic biofuels that utilize the woody or fibrous parts of plants (Figure 1). The EU has cited the negative impacts of first-generation crops, such as deforestation, competition with food production and indirect land use change, as a justification for shifting towards cellulosic biofuels (European Parliament and Council of the European Union, 2015). However, cellulosic energy crops can have a range of different impacts on ecosystem services (Holland et al., 2015) and there is a need for more targeted policy development if cellulosic energy crops are to live up to their full potential.

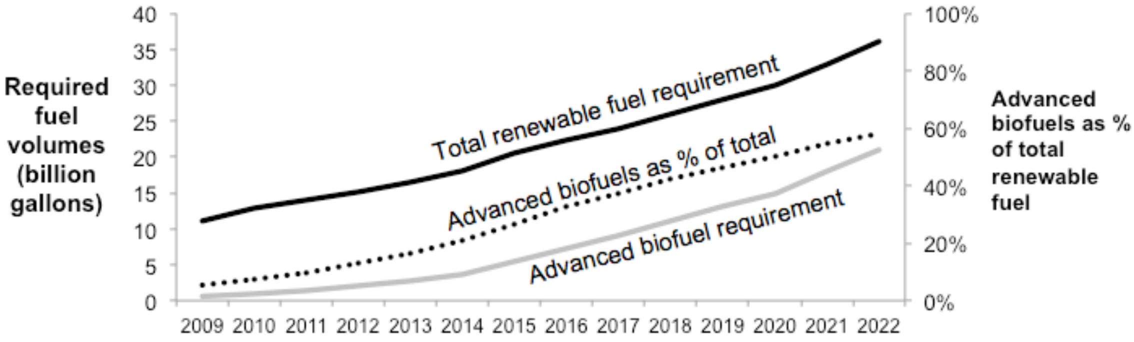

Figure 1 [two column image]**: Increase in advanced biofuel requirement in the US 2009-2022.** Data source: Environmental Protection Agency (2010). Advanced

biofuels include cellulosic biofuel, biomass-based diesel and other biofuels with >50% GHG savings.

The aim of this article is not to argue for the universal support of all energy crops on the assumption that they will lead to the generalized enhancement of all ecosystem services. Rather, it is to identify policy mechanisms that could be used to promote specific land use activities capable of jointly delivering bioenergy outputs alongside other ecosystem services relating to soils, water, biodiversity or other ecosystem features. This notion of joint delivery of outputs can be framed in terms of "multifunctionality" (OECD, 2001) or "coupling" within complex human and natural systems (Liu et al., 2007). However, while some land use practices may be capable of jointly benefitting a number of ecosystem services simultaneously, in other cases the core provisioning service of the land use (e.g. food, fibre or bioenergy provision) may be linked to a range of "disservices", or declines in ecosystem services (Power, 2010). As such, the following section explores the range of impacts that energy cropping can have on the different dimensions of ecosystem services, both positive and negative, before moving on to a consideration of policy mechanisms.

1.1 How can energy crops enhance or degrade ecosystem services?

Table 1 provides examples of energy cropping systems that have been shown to enhance or degrade specific ecosystem services, following the ecosystem services categorization applied by the Millenium Ecosystem Assessment (2003). These examples are intended to demonstrate the diversity of ways in which energy crops can impact ecosystem services. They are not intended to provide an exhaustive list of all possible impacts or indicate the likelihood of energy crops enhancing or degrading ecosystem services overall. More comprehensive reviews of the links between energy cropping and ecosystem services have been undertaken by Gasparatos et al. (2011), Holland et al. (2015) and Baumber (2016), with each review highlighting that impacts are dependent on the specific context and management practices employed.

Table 1 [two column table]: Dimensions of ecosystem services most affected by energy cropping

Ecosystem services categories	**Dimensions most affected by energy cropping**	**Examples of energy cropping systems that have been shown to:**	
		degrade ecosystem services	**enhance ecosystem services**
Supporting services	Soil formation, nutrient cycling, habitat provision	Risk of soil loss from intensification of corn production for methane on loess soils in Germany (Lupp et al., 2015)	Short rotation coppicing of poplar and willow in Europe with benefits for habitat and soils (Dimitriou et al., 2011; Maletta and Lasorella, 2014)
Regulating services	Climate regulation and water regulation/ purification	Palm oil biodiesel contributing to greenhouse gas emissions through deforestation in Indonesia and Malaysia (Gao et al., 2011)	Increased carbon sequestration from sugarcane grown on degraded land in Brazil (Lange, 2011)

Provisioning services	Fuel provision, food provision	Jatropha established for biodiesel at the expense of local food production in the Philippines (Anseeuw et al., 2012)	Mallee eucalyptus plantings to mitigate salinity and maintain wheat production in Western Australia (Bartle et al., 2007)
Cultural services	Aesthetics, social relations, sense of place	Negative stakeholder perceptions of tree crops such as willow in heath and meadow landscapes in Germany (Boll et al., 2014)	Positive stakeholder perceptions around the aesthetics of miscanthus crop expansion in England (Dockerty et al., 2012)

While the examples in Table 1 demonstrate how specific energy crops can impact specific ecosystem services, in practice it is common for energy cropping systems to impact multiple ecosystem services simultaneously. For example, deforestation for oil palm expansion does not only impact regulating services by releasing carbon to the atmosphere and altering evapotranspiration rates, but may also impact supporting services through habitat loss and soil erosion (Sheil et al., 2009) and cultural and provisioning services through dispossession of local people and the resulting loss of food security (Colchester, 2011). Conversely, belts of mallee (eucalyptus) trees have shown the potential to enhance regulating services by preventing the rise of saline groundwater (Figure 2), enhance provisioning services by allowing wheat production to be maintained (Bartle et al., 2007), enhance supporting services by providing additional habitat in highly-cleared landscapes (Smith, 2009) and enhance cultural services by improving aesthetics and helping farmers remain on the land (Baumber et al., 2011).

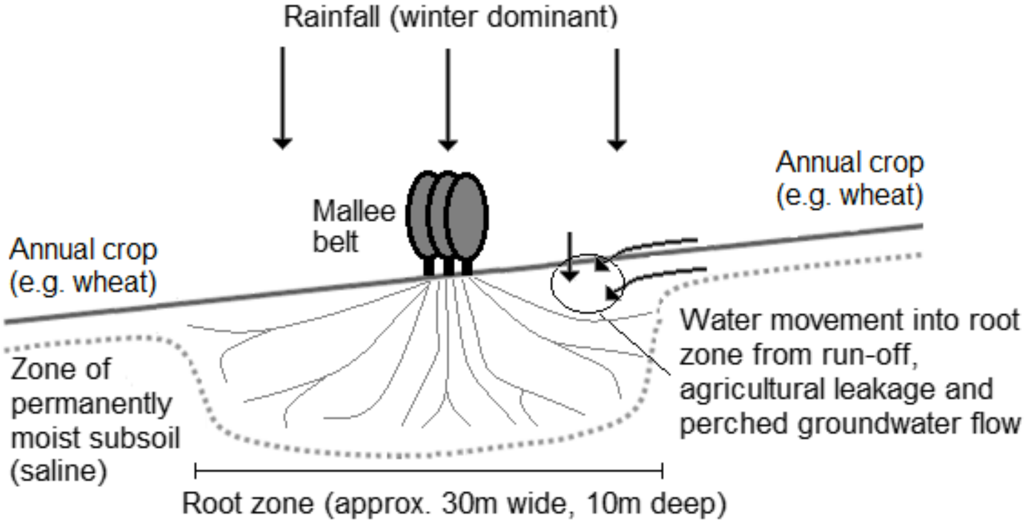

Figure 2 [two column image]**: Using mallee tree belts to mitigate dryland salinity in the wheatbelt of Western Australia.** Adapted from Yu et al. (2007).

Some of the most prominent examples of energy crops enhancing ecosystem services involve willow and poplar grown in short rotation coppice (SRC) systems in Europe and North America. These are largely grown for electricity and heating fuels, but also have the potential to supply biomass for advanced (second-generation) biofuels such as cellulosic ethanol. These systems have been shown to not only provide supporting services through habitat provision for deer, birds and bees (Dimitriou et al., 2011) and increases in soil organic matter relative to annual crops (Maletta and Lasorella, 2014), but to also enhance regulating services by filtering wastewater (Schroeder, 2012) and remove heavy metals such as cadmium and zinc from contaminated soils (Van Slycken et al., 2012).

Energy cropping systems involving perennial trees, shrubs or grasses are more commonly associated with the enhancement of ecosystem services than annual crops like wheat, corn or soy. As perennial SRC crops (e.g. willow or eucalyptus) can be coppiced and do not require replanting each year, they have the potential to establish more extensive root systems, better protect soils, provide more stable habitat and reduce disturbances from tilling that can lead to soil erosion and water pollution (Dimitriou et al., 2011; Lowrance and Davis, 2014). Perennial grasses such as miscanthus and switchgrass have also been shown to increase soil infiltration, sequester carbon and reduce erosion relative to annual cropping systems (Lowrance and Davis, 2014). Miscanthus crops can enhance soil stability by producing dense rhizomes that reach depths of 2.5 metres (Brancourt-Hulmel et al., 2014). Switchgrass has been targeted as a potential energy crop for marginal land in the US Great Plains, where it could not only help to protect soils, but also provide habitat for wildlife and increase landscape heterogeneity (Hartman et al., 2011).

While research into SRC crops highlights their potential to be targeted at the enhancement of selected ecosystem services, it also demonstrates that impacts are dependent on the local context, the prior use of the land and the management practices employed (Simpson et al., 2009). Climate regulation may be enhanced through carbon sequestration if SRC crops are planted on former cropland (Lockwell et al., 2012), but this benefit may not be replicated if SRC crops are established on grassland (Lowrance and Davis, 2014). Similarly, the impacts on cultural services are context-specific, with Boll et al. (2014) reporting that attitudes towards SRC crops in Germany varied according to the land use patterns of the area (i.e. support was lower in areas dominated by meadows that in areas with more forested land). Simpson et al.

(2009) found that SRC crops are more likely to enhance regulating and supporting services if crop management is focused on landscape heterogeneity (e.g. multiple species and ages), strategic placement in the landscape (e.g. wildlife corridors and buffers) and careful timing of disturbances such as harvesting.

In their review of lignocellulosic (second-generation) energy crop impacts on ecosystem services, Holland et al. (2015) found evidence of significant benefits where these woody or fibrous crops are planted on land previously used for annual crops. However, they also found that ecosystem services are likely to be negatively impacted if forests are converted and that the impacts of converting marginal land are variable and uncertain. Similarly, oil palm for biodiesel has been linked to tropical deforestation in Southeast Asia (Sheil et al., 2009), but can produce different outcomes when planted on previously-cleared land. Koh et al. (2009) argue that oil palm agroforestry has the potential to offer a form of “wildlife-friendly farming” if established as low density plantings with a mix of other species in a landscape mosaic and the Brazilian Government has introduced a range of initiatives to guide oil palm expansion towards degraded land in the Amazon region (Villela et al., 2014).

One final point to consider before moving on to policy is the management of trade-offs. Some trade-offs have already been highlighted, such as the trade-off between energy production (a provisioning service) and loss of forests and other land types that provide multiple ecosystem services. Another prominent trade-off is around “food vs fuel”, which has been the subject of much debate, especially at times of rising global food prices (e.g. Eide, 2008). While “food vs fuel” has been criticized for being “overly simplistic” (UN Energy, 2007 p. 31) and some forms of energy cropping may actually be able to enhance long-term food provision, such as the aforementioned mallee cropping system in Western Australia (Bartle et al., 2007), trade-offs between food and fuel are likely to be required in certain contexts and require consideration in policy development. Schulze et al. (2016) provides a specific example from Germany, arguing that a substantial increase in SRC energy crops could enhance biodiversity and regulating services but cause a decline in food production.

Managing trade-offs is complicated by the fact that some impacts of energy cropping are indirect. Due to the interconnected nature of global energy and food markets, land use changes in one location that affect the supply of energy, food and other agricultural commodities may result in land use change in other, distant locations (Berndes et al., 2011). This process of indirect land use change (iLUC) has attracted much attention in bioenergy policy development in recent years (e.g. European Parliament and Council of the European Union, 2015) and adds an additional dimension to the consideration of trade-offs, as enhancements of ecosystem services in one part of the world may be offset by declines in other locations as land use patterns shift in response to global commodity markets.

1.2 Policy tools for the enhancement of ecosystem services

Bioenergy policy-makers looking to promote forms of energy cropping that enhance ecosystem services are fortunate to be able to draw on a rich body of knowledge on policy tools that can be used to promote ecosystem services. For example, Braat and de Groot (2012) outline key policy principles that underpin the ecosystem services concept, such as “no net loss, “polluter pays” and “beneficiary pays”. Recent policy reviews include an analysis of opportunities and barriers around incorporating the ecosystem services concept into EU policy (Schleyer et al., 2015) and a review of decision-support tools to operationalize the ecosystem services in different industry sectors (Grêt-Regamey et al., in press).

Policy mechanisms to enhance ecosystem services can be categorized in a number of different ways, including based on whether they provide positive or negative incentives and the degree to which they incorporate market principles (Figure 3). Under the framework shown in Figure 3, the main determinant for the placement of a policy instrument on the “market-based” axis is the degree to which it allows prices to be set by markets (e.g. through the use of auctions or the creation of markets for offsets) rather than being set by government (e.g. through fixed payments or penalties). However, fixed-price instruments may also be considered market-based where they involve multiple buyers or sellers of ecosystem services (Baumber, 2017).

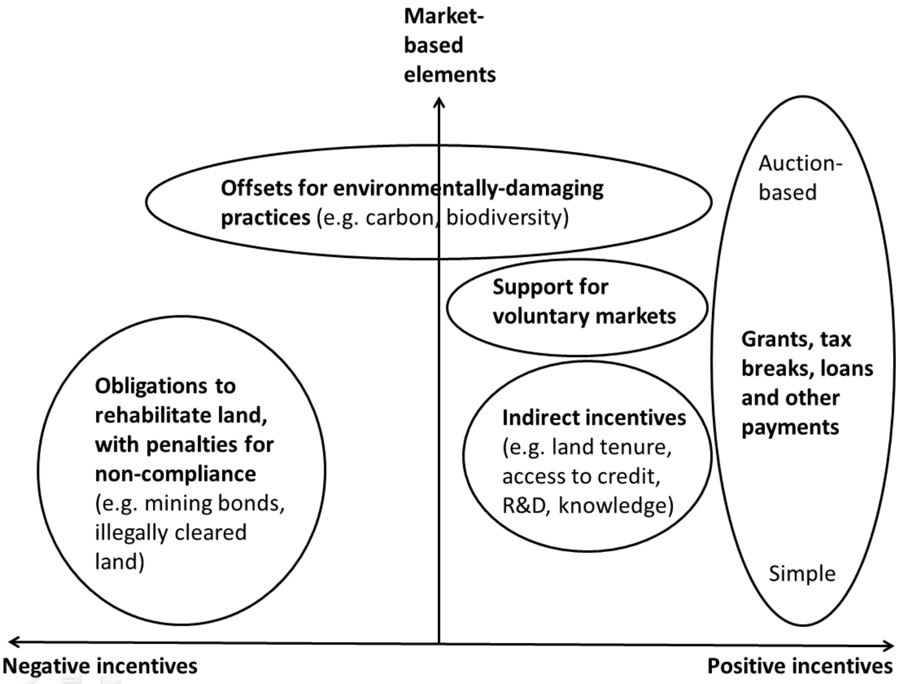

Figure 3 [two column image]**: Examples of policy measures that can be used to enhance ecosystem services.** Policy measures are categorized based on the nature of the incentives provided (horizontal axis) and the degree to which they incorporate market principles (vertical axis).

Positive incentives may involve grants, loans, tax breaks or non-financial incentives that induce landholders or other stakeholders to undertake actions that enhance ecosystem services. In contrast, negative incentives involve an obligation being placed on land managers to provide ecosystem services under threat of financial or other penalty, with an example being minesite reclamation bonds that incentivize compliance with restoration obligations, while also providing a potential source of public funds for restoration if required (Gerard, 2000). Positive incentives such as grants or tax breaks employ the "beneficiary pays" principle (with governments acting as the beneficiaries on behalf of their citizens), while negative incentives such as reclamation bonds employ the "polluter pays" principle (Braat and de Groot, 2012). Many of the policy instruments shown in Figure 3 have analogues in the renewable energy sector, including positive incentives such as grants and payments for bioenergy production and negative incentives such as biofuel mandates or renewable electricity quota obligations with penalties for non-compliance (REN21, 2016).

Restoration grants offered by government agencies (e.g. US Fish and Wildlife Service), inter-governmental bodies (e.g. UN Global Environment Facility) or non-government organizations (e.g. WWF) represent positive incentives to enhance ecosystem services. However, indirect or non-financial benefits may also be provided, such as preferential access to credit from state-owned banks (e.g. in Brazil; Stickler et al., 2013) or increased security of land tenure (e.g. in Indonesia; OECD, 2010). Grants programs also vary based on the degree to which they employ market-based approaches to enhance the cost-effectiveness of public spending or to provide increased flexibility to affected stakeholders.

Auction approaches are a common way of enhancing the cost-effectiveness of public spending, such as the “reverse auction” used by the US Conservation Reserve Program (CRP) to award payments to landholders (Hellerstein et al., 2015). The OECD (2010) analyzed case studies from the US, Australia and Indonesia where reverse auctions have been used to distribute environmental grants and found a strong case that they can enhance cost-effectiveness compared to allocating grants on a “first-come first-served” basis. This represents another area of overlap with the renewable energy sector, where auction-based approaches are increasingly being used to enhance the cost-effectiveness of government energy purchases or public financing for new facilities (REN21, 2016).

Most of the policy measures on the right-hand side of Figure 3 meet the definition of payments for ecosystem (or environmental) services (PES). According to Wunder (2005), the criteria for PES are that the arrangement is voluntary, involves at least one ‘seller’ and one ‘buyer’, and is conditional on the delivery of a well-defined environmental service (or land use activity likely to secure that service). While the simplest examples involve one buyer, such as a government agency providing grants to providers of ecosystem services, it is also possible to set up markets to trade in ecosystem services. Costa Rica provides a prominent example of a PES scheme that combines government procurement, voluntary purchases from private companies (mostly hydroelectric plants) and purchases from overseas companies wishing to offset their regulatory obligations around greenhouse gas emissions (Porras et al., 2013).

Offset markets combine positive and negative incentives by placing regulatory restrictions on certain activities that degrade ecosystem services (e.g. emitting greenhouse gases or clearing forests) but then allowing some flexibility for these activities to continue if an offsetting action is undertaken elsewhere. This can include carbon offsets such as tree-planting to offset greenhouse gas emissions, as well as biodiversity offsets (e.g. the BioBanking scheme in the Australian state of New South Wales) and offsets related to other ecosystem services. Such schemes often follow the "no net loss" principle, which was pioneered in the US in relation to wetlands in the 1970s (Doswald et al., 2012) and represents a key agenda item for the advancement of the ecosystem services concept (Braat and de Groot, 2012). Carbon offsets are of most direct relevance to bioenergy, as carbon pricing schemes can be designed to incentivize both the creation of carbon offsets through biosequestration and the provision of bioenergy as a low-emission alternative to fossil fuels (e.g. Clean Development Mechanism of the Kyoto Protocol).

Lastly, policy-makers may choose to not directly provide incentives or disincentives for on-ground actions but may instead provide education and technical support, research and development funding or institutional support. The Forestry Reclamation Approach developed for the Appalachian coal mining industry in the US is an example of technical support to assist ecosystem service provision in mine reclamation (Zipper et al., 2011). Research and development may be undertaken directly by government agencies or by multi-stakeholder bodies such as CGIAR (Consultative Group on International Agricultural Research), whose Water, Land and Ecosystems program is funded by Australia, The Netherlands, Sweden and Switzerland (CGIAR, 2016). Costa Rica's PES program also highlights the importance of institutional support for voluntary markets, with the National Fund for Forest Financing (FONAFIFO) playing a key role in managing market arrangements and assigning certificates for greenhouse gas mitigation, hydrological services, biodiversity conservation and scenic beauty (Le Coq et al., 2015).

2. Research aims and methods

The aims of this review are to: (1) Identify existing bioenergy policy measures that promote active enhancement of ecosystem services; and (2) Identify further opportunities to adapt bioenergy support policies to preferentially promote forms of energy cropping that are capable of enhancing ecosystem services.

A three-stage methodology was employed to achieve these aims, as follows:

1) Identifying policy instruments most commonly used to promote bioenergy globally.
2) Identifying design features incorporated into past and present bioenergy policies that preferentially support forms of energy cropping that enhance ecosystem services.
3) Identifying further opportunities to modify common bioenergy policy instruments to incorporate incentives for ecosystem service enhancement.

All stages were global in scope an included all end uses of bioenergy, including transport fuels, electricity and heat. Consideration was given to both established and emerging energy crops and conversion pathways, but particular attention was paid to perennial grasses and woody crops due to their demonstrated capacity to enhance ecosystem services in specific contexts (Lowrance and Davis, 2014; Maletta and Lasorella, 2014; Simpson et al., 2009).

The selection of literature for Stage 1 took into account the different roles of government agencies in developing and communicating policy, academic authors in undertaking policy research and various industry and inter-governmental bodies in reporting on, analyzing and recommending policy. In order to identify existing bioenergy policies that promote ecosystem service enhancement (Stage 2) and identify further opportunities (Stage 3), three primary information sources were used, as follows:

1) The Thomson Reuters Web of Science database of academic journal articles and other publications, which was searched using the terms “ecosystem services” & “bioenergy” & “policy” (61 results).
2) Websites of key international institutions, including REN21, IEA Bioenergy, The World Bank, The Organisation for Economic Co-operation and Development, The Centre for International Forestry Research (CIFOR) and the United Nations Environment Programme (http://www.unep.org/publications). The search term for IEA Bioenergy was “ecosystem services” while for the other four sites it was “bioenergy”.
3) A selection of recent books on energy cropping identified through an internet search (Google search engine), including Halford and Karp (2011), Kole et al.

(2012), Singh (2013), Karlen (2014), Langeveld et al. (2014) and Baumber (2016).

Search results were reviewed manually to identify examples of bioenergy policy mechanisms that have been or could potentially be adapted to preferentially support energy crops that enhance ecosystem services. The initial batch of academic publications and reports identified through the database and website searches were added to by following relevant citations to other articles, reports, policy documents and legislation.

3 Policy tools commonly used to promote bioenergy

To assist with the analysis of bioenergy policies, Table 2 categorises renewable energy policy instruments according to the policy framework used by the renewable energy policy network REN21, with examples of how each policy type can be used to support energy cropping. The REN21 framework divides policy measures into two main categories ("regulatory policies" and "fiscal incentives and public financing"), with twelve policy instrument types across the two categories (REN21, 2016). In Table 2, three additional policy instrument types have been added to those from the REN21 framework under the category of "other". These policies do not provide direct financial support for energy crops but can assist in their promotion.

Table 2 [single column table]: Major categories of renewable energy support policies. Categorization framework from REN21 (2016)

Category	Policy instrument	Example of use to support energy crops
Regulatory	Transport obligation /	Fuel suppliers obligated to supply a set volume

Category	Policy instrument	Example of use to support energy crops
policies	mandate	or proportion of biofuel
	Electric utility quota obligation / Renewable Portfolio Standard (RPS)	Electricity companies obligated to provide a set quantity or proportion of renewable electricity (with energy crops an eligible source)
	Tradable REC (Renewable Energy Certificate)	Electricity companies allowed to meet their renewable obligations by purchasing RECs from other parties undertaking the generation.
	Heat obligation/mandate	Heat suppliers required to provide a set amount or proportion of renewable heat (with energy crops an eligible source)
	Tendering	Government agencies tender for desired renewable electricity or fuel quantities or capacities, with energy crops as an eligible source.
	Feed-in tariff / premium payment	Electricity companies obligated to purchase eligible generation (including from energy crops) at fixed tariffs/prices set by government
	Net metering /net billing	Electricity consumers able to offset their use of grid electricity by exporting electricity back to the grid
Fiscal incentives and public financing	Reductions in sales, energy, valued added tax (VAT) or other taxes	Fuel taxes lowered for biofuels relative to fossil fuels
	Investment or production tax credits	Investors in bioenergy facilities able to claim tax credits for their investment
	Energy production payment (including auction-based payments)	Electricity generators paid per unit of eligible generation, with energy crops as eligible source
	Capital subsidy, grant, or rebate	Governments cover some of the costs of investing in bioenergy capital costs
	Public investment, loans, or grants (including for research)	Governments make direct investments in bioenergy facilities or research
Other (not listed by REN21)	Carbon pricing	• Price of fossil fuel energy raised relative to bioenergy • Energy crops able to earn payments as eligible offsets for fossil fuel use
	Knowledge and technical support	Governments support energy crop development through non-financial support
	Institutional support for voluntary markets	Governments establish frameworks and standards to facilitate voluntary purchases of renewable energy (including from energy crops)

Figure 4 maps energy crop support policies according to whether they provide positive or negative incentives and the degree to which they incorporate "market-based" features. This replicates the approach taken in Figure 3 for ecosystem service policies. As with Figure 3, policies have been placed higher on the market-based axis if they allow prices to be set by the market (e.g. tradable RECs or auction-based approaches) rather than by regulations (e.g. fixed subsidies or feed-in tariffs).

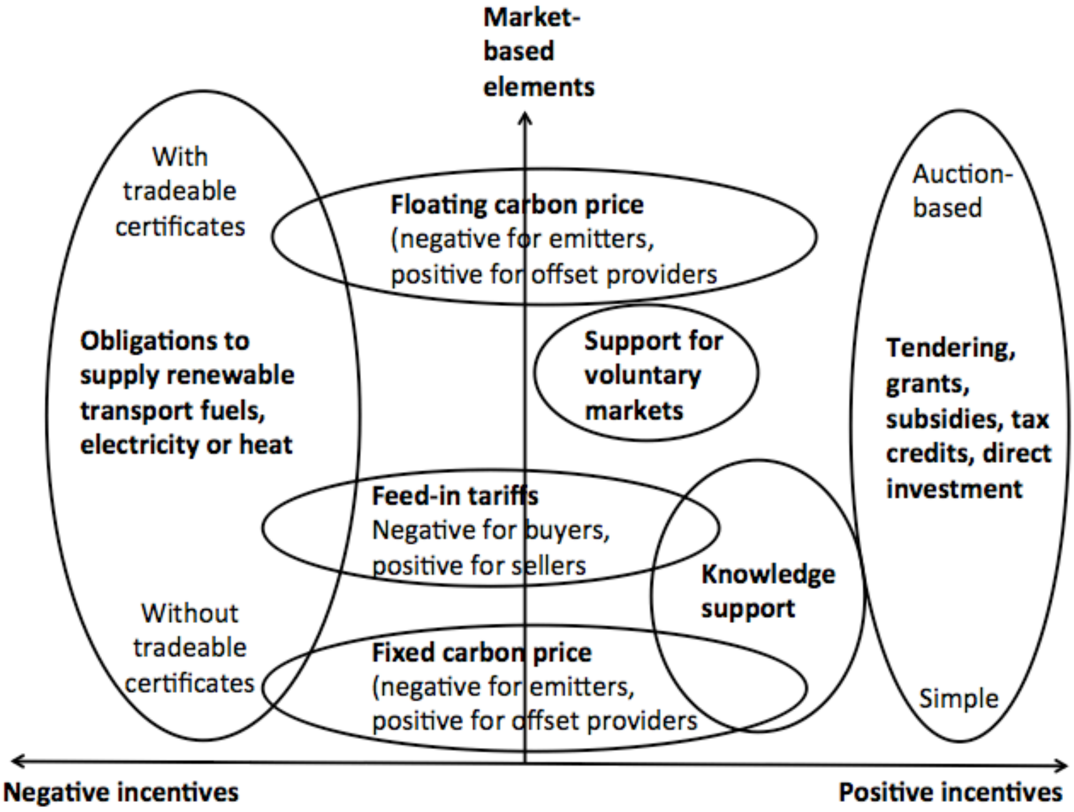

Figure 4 [two column image]**: Renewable energy policy instruments mapped by nature of incentives and market-based features.**

Policies classed as "regulatory" by REN21 (e.g. biofuel mandates) appear mostly on the negative incentive side of Figure 4 due the obligations they place on energy companies (with penalties for non-compliance). Conversely, fiscal incentives such as grants and tax credits offer a positive incentive to supply bioenergy.

It is common for different bioenergy support policies to be combined to simultaneously provide both a “carrot” and a “stick”. One such example is ethanol in the US, whereby production was promoted by granting a tax credit of 45 cents per gallon to US-based ethanol fuel blenders, with consumption encouraged through fuel use mandates imposed by the Renewable Fuel Standard (RFS). After the tax credit ended in 2011, the RFS continued to oblige refiners and importers to use set volumes of ethanol. In addition, these policies have been supported by a range of other federal and state incentives targeted at research and development, crop establishment and capital investment in production facilities (US Department of Energy, 2016).

While the term “mandate” is commonly used for transport fuels, similar schemes in the electricity sector tend to be referred to as “quota obligations” or “Renewable Portfolio Standards” (RPS). Such schemes generally cover more than just bioenergy. For example, under the UK Renewables Obligation (RO), energy crops represent one eligible source alongside wind, solar photovoltaics, hydropower and other forms of renewable generation. Mandates can also be used to promote renewable heat (e.g. from biomass-fired combined heat and power plants) or renewable gas (e.g. biogas, syngas).

Feed-in-tariffs (FiTs) are an alternative to mandates for promoting renewable electricity generation. Rather than fixing the amount of renewable generation that an energy company must generate or procure, they instead fix the price that energy companies must pay for eligible generation. While FiTs have been most prominent around rooftop solar photovoltaic systems (Cory et al., 2009), they have also been used to promote bioenergy generation in countries such as Germany (Wilkinson, 2011). Net metering is a simpler method whereby a utility subtracts the amount of electricity a producer exports to the grid from the amount they import from the grid.

Efficiency and cost-effectiveness are critical considerations in the choice and design of renewable energy policies. In terms of regulatory policies, Azuela et al. (2012) report that the "general consensus" is that FiTs reduce risks to investors, while obligations or mandates are often able to deliver renewable energy that is less expensive overall. Mandates and quota obligation schemes may incorporate tradable certificates to enhance efficiency and provide flexibility for liable parties. For example, Australia's Renewable Energy Target (RET) mandates the generation of required amounts of renewable generation, but allows liable parties to meet their obligations by purchasing certificates from other parties rather than generating the electricity themselves (Office of the Renewable Energy Regulator, 2011).

For fiscal incentives and public financing, governments may employ tendering or auction approaches that involve competitive bidding to enhance cost-effectiveness, with the use of such mechanisms expanding in recent years (REN21, 2016). As with the CRP example cited in section 1.2, such auctions are more accurately referred to as "reverse" or "inverse" auctions, as they involve multiple interested suppliers bidding to provide renewable energy for the lowest price (per MWh supplied or per MW of capacity installed). More complex auction designs may involve the calculation of an index that incorporates other factors such as benefits to the local economy and the track record of bidding companies (Azuela et al., 2014). Auctions may also be used in combination with mandates, such as in Brazil, where government-run biodiesel auctions help to deliver security of supply and stable pricing for fuel suppliers with biofuel mandate obligations (Barros, 2014).

In addition to the policy instruments recorded in the REN21 database, other support options can include knowledge support and institutional support for voluntary markets. Knowledge-sharing and technical support can assist industry development without direct financial payment from governments. Similarly, institutional support for voluntary markets may enable consumers to voluntarily support renewable energy. An example is Australia's Greenpower program, whereby a government entity manages the market and certifies renewable energy certificates, but the financial support comes from consumers on a voluntary basis (Greenpower, 2016). This arrangement is not dissimilar to Costa Rica's PES program, whereby the National Fund for Forest Financing (FONAFIFO) certifies voluntary PES credits for greenhouse gas mitigation, hydrological services, biodiversity conservation or scenic beauty (Le Coq et al., 2015).

A final measure that is not recorded in the REN21 database is carbon pricing, which represents an "indirect" renewable energy support mechanism (Azuela et al.2012). While the support for renewable energy is not direct as under a mandate or grant scheme, carbon pricing can incentivize energy crop investment in two important ways. Firstly, it can increase the cost of competing energy sources with high greenhouse gas emissions such as coal. Secondly, it can incentivize plantation establishment by awarding credits for the carbon sequestered relative to that which existed in the land unit previously.

Carbon pricing can take a variety of forms, which is why it appears in multiple parts of the policy map in Figure 4. Carbon pricing schemes may be designed around negative incentives by placing a tax or cap on emissions (such as under the EU Emissions Trading Scheme) or they may be designed to provide positive incentives by offering government payments for offsets or abatement (such as Australia's Emissions Reduction Fund). Another key variable is the amount of trading permitted between liable parties (i.e. subject to emission caps or charges) and providers of offsets and abatement.

4 Examples of bioenergy policies that incentivize ecosystem service enhancement

The most common ecosystem services cited in bioenergy policy design are the provision of fuel (a provisioning service) and the mitigation of climate change (a regulating service). For example, energy security (or "energy independence") is commonly listed as a reason for promoting energy cropping in the United States (e.g. Biofuels Interagency Working Group, 2010). In contrast, climate change mitigation through fossil fuel substitution is listed as the primary objective of the European Union's Renewable Energy Directive (RED), which sets national targets for renewable transport fuel and electricity use in EU member states (European Parliament and Council of the European Union, 2009). As energy provision is an objective of all bioenergy support policies, the focus of this article is on the extent to which bioenergy policies promote other ecosystem services, including regulating services (e.g. climate regulation and water purification), supporting services (e.g. soil protection and habitat provision) and cultural services (e.g. aesthetics and attachment to place).

One mechanism for preferentially supporting energy crops that contribute the most to climate change mitigation is a sub-mandate or sub-quota approach. This involves setting a mandate or quota obligation for transport fuels, electricity or heat, but splitting it into separate sub-mandates or sub-quotas with different eligibility rules. The US Renewable Fuel Standard (RFS) provides an example of this approach, with its separate mandates for advanced and non-advanced fuels (Figure 1). The key parameter used to define “advanced” biofuels under the RFS is life-cycle greenhouse gas savings relative to fossil fuels, with a 60% saving required for cellulosic biofuels and a 50% saving required for other advanced biofuels (Environmental Protection Agency, 2010).

When assessing biofuel “pathways”, the US EPA takes into account the types of land on which energy crops are likely to be grown, including whether they are likely to increase or decrease carbon stocks in vegetation and soils (Environmental Protection Agency, 2010). While this approach provides some incentive for energy crops that increase carbon stocks (a regulating service), it does not consider the enhancement of other ecosystem services such as habitat provision or watershed protection. Furthermore, some energy cropping systems that actually reduce soil carbon may still comply with an approved pathway for cellulosic biofuels, as the EPA assumes typical practices based on feedstock type and conversion process rather than requiring each energy cropping operation to be individually certified.

An alternative to the use of sub-mandates is “banding”, whereby energy produced using certain technologies or production systems count for more than other forms of energy against relevant targets, mandates or quota obligation schemes. For example, the EU RED allows biofuels from wastes or cellulosic feedstocks (including grasses and woody crops) to be counted for double their actual energy content against national targets. While this encourages the production of cellulosic energy crops over first-generation crops, it does not differentiate between cellulosic crops that enhance ecosystem services and those that do not.

Aside from biofuels, banding has also been applied to renewable electricity generation in two EU member states, the United Kingdom (UK) and Italy (Gürkan and Langestraat, 2014). In the UK, the Renewables Obligation provides a greater incentive for electricity generation from energy crops than for other forms of bioenergy (Table 3). However, the primary motivation behind this approach is not to encourage energy cropping that enhances ecosystem services, but rather to assist the development of technologies that are more expensive at present but have the potential to make a substantial contribution to renewable energy supply over the longer-term (Gürkan and Langestraat, 2014).

Table 3 [single column table]: Banding arrangements for selected bioenergy sources under the UK Renewables Obligation for 2016/17. Source: OFGEM (2013)

Generation type	**Credits per MWh**
• Co-firing of biomass other than energy crops (low-range)	0.5
• Co-firing of relevant energy crops (low range)	1

• Dedicated biomass	1.4
• Dedicated energy crops	1.8

Carbon pricing may be used to indirectly support energy crops that reduce fossil fuel use and sequester carbon in vegetation and soils. However, some schemes, such as the EU's Emissions Trading Scheme, do not recognise sequestration from reforestation activities or plantations (including energy crop plantations) due to concerns around a lack of appropriate and harmonised data and reporting systems (European Commission, 2012).

In contrast to the EU ETS, the Clean Development Mechanism (CDM) and Joint Implementation (JI) provisions of the Kyoto Protocol allow stakeholders in developed (Annex I) countries to earn carbon credits by investing in reforestation and afforestation projects elsewhere (including projects that include some harvesting for energy). However, concerns have been raised that the CDM lacks flexibility and that simpler methodological and documentation procedures are required to facilitate CDM reforestation projects (Thomas et al., 2010). Conversely, some CDM reforestation projects involving energy production have been criticized for insufficient regulation, such as a charcoal production project involving the Plantar Group in the Brazilian state of Minas Gerais (Watch, 2010).

An example of how governments can assist with methodological and documentation procedures around carbon offsets can be found under Australia's Emissions Reduction Fund. This fund involves the Australian Government purchasing certified emissions reductions through a reverse auction process. The government's Clean Energy Regulator has developed specific methodologies for harvested plantations that could enable perennial energy cropping systems to earn credits for the carbon they sequester. For harvested plantations (whether for energy or other products), proponents are required to model the average carbon stocks over the life of a project relative to a baseline (i.e. carbon stocks prior to plantation establishment), taking into account variations due to harvest cycles (Clean Energy Regulator, 2015).

For ecosystem services other than energy provision and climate regulation, bioenergy policies generally frame energy cropping as a threat rather than an opportunity for enhancement. For example, the EU RED emphasizes that biofuels can contribute to the destruction of forests, wetlands or areas of high biodiversity value and provides eligibility criteria that prevent biofuels that contribute to these threats from being counted towards national renewable energy targets. In addition, biofuels from food crops, which could pose a threat to food security (a provisioning service) are capped at 7% of the overall transport fuel target (European Parliament and Council of the European Union, 2015). Similarly, non-government biofuel certification schemes such as that of the Roundtable on Sustainable Biomaterials (RSB) require biofuel producers to demonstrate that their production systems do not pose a threat to biodiversity, soils or water quality (Roundtable on Sustainable Biomaterials, 2011). The RSB standard has been approved for the assessment of biofuel sustainability under the EU RED and for the biofuel mandates in the Australian state of New South Wales (NSW Fair Trading, 2016).

While the EU RED sustainability criteria predominantly frame energy cropping as a potential threat to soils and water quality, the RED also recognizes that some energy crops have the potential to enhance soil protection (a supporting service) and water filtration (a regulating service). This is reflected in the statement that some forms of energy cropping have the “potential to contribute to the restoration of severely degraded and heavily contaminated land” (European Parliament and Council of the European Union, 2015 p. L239/5).

The mechanism by which the RED seeks to incentivize energy crops capable of achieving restoring degraded and contaminated land is through its carbon accounting rules. Under these rules, biofuel feedstocks may qualify for a “bonus” if they are grown on restored degraded land, which could potentially make it easier for a biofuel producer to satisfy the RED’s minimum greenhouse gas saving requirements (60% saving compared with fossil fuels for post-2015 installations). However, the RED amendments of 2015 emphasize the high level of uncertainty around actual land-use change impacts (European Parliament and Council of the European Union, 2015) and a lack of final European Commission guidance on what land will qualify for the bonus has prevented its inclusion in greenhouse gas calculation systems for the RED (Roundtable on Sustainable Biomaterials, 2015). Thus, as of the time of writing, the RED bonus for restoring degraded land was yet to be operationalized.

Where feed-in tariffs are used to promote renewable electricity generation, they can also be designed to provide a greater incentive for certain technologies and energy sources over others. An example of a country that has used feed-in tariffs in this way is Germany, where feed-in tariffs have been set at different levels to preferentially support energy crops over manure, small-scale generation over large-scale generation and advanced technologies such as fuel cells (Table 4). While biomass grown for energy qualifies for a bonus tariff regardless of whether it enhances or degrades ecosystem services, there is an additional bonus for biomass sourced from land managed under Germany's Compensation Scheme for Market Easing and Landscape Protection, which is aimed at the preservation of agricultural landscapes for both environmental and cultural reasons (Troost et al., 2015), which could include regulating, supporting and/or cultural ecosystem services.

Table 4 [two column table]**: Use of differentiated feed-in tariffs to promote bioenergy in Germany.** Adapted from Wilkinson (2011)

Generation capacity (kW)	**Tariff as of December 2010 (€ cents/kWh)**				
	Base rate	**Bonuses for:**			
		Biomass specifically grown for energy	**Manure**	**Landscape preservation**	**Advanced technology (e.g. fuel cells, gas turbines)**
< 150 kW	11.55	6.93	3.96	1.98	1.98
150 - 500 kW	9.09	6.93	0.99	1.98	1.98
500 - 5000 MW	8.17	3.96			1.98

Bioenergy-related grants, loans and tax breaks have the potential to be structured so as to preferentially support energy crops that enhance multiple ecosystem services (i.e. more than just energy provision and climate regulation), but few examples were identified by this review. The most notable example is Brazil's National Programme on the Production and Use of Biodiesel (PNPB), which employs a social fuel label ("Combustível Social") that allows biodiesel producers to claim a higher fuel tax reduction if their feedstock is sourced from small family farmers covered by the National Programme for the Strengthening of Family Agriculture (PRONAF) or produced in priority regions in the country's north and north-east (Barros, 2014). The focus on family farming recognizes the cultural service that such land use activities may provide, but the scheme does not provide additional incentives for ecosystem service enhancement around soil health, water quality or biodiversity.

Research and development grants or other support may be targeted at perennial energy crops with a range of ecosystem service benefits. For example, in Australia the Future Farm Industries Cooperative Research Centre has targeted dryland salinity through research into energy crops that could increase evapotranspiration rates (Future Farm Industries CRC, 2011). In addition, the Forest Industries Climate Change Research Fund has funded research into woody energy crops with the potential to reduce soil erosion and provide habitat in the state of New South Wales (Baumber et al., 2012).

In summary, it is common for bioenergy policies around the world to promote energy crops that supply renewable energy (a provisioning service) and help to mitigate climate change through fossil fuel replacement and biosequestration (a regulating service). However, for most other ecosystem services, bioenergy policies generally frame energy crops as a threat. A review of the academic literature, reports and policy documents reveals a small number of exceptions, including the EU’s degraded land bonus (yet to be operationalized), Germany’s feed-in tariff bonus for landscape preservation, Brazil’s additional tax breaks for biofuel feedstocks that provide cultural services, the preferential support for cellulosic energy crops under the EU RED and the US RFS and research funding for woody energy crop development in Australia and other countries.

5 Opportunities to further incentivize ecosystem service enhancement through modifications to bioenergy policies

While some bioenergy support policies provide incentives for the enhancement of ecosystem services, further opportunities exist to expand the range of ecosystem services that are targeted, to remove barriers to the effectiveness of these measures and to modify other types of policy instruments to achieve multiple objectives. These opportunities exist across the full range of policy instruments cited in the previous section, including mandates and quota obligations, feed-in tariffs, carbon pricing, grants and tax concessions.

With regards to biofuel mandate schemes such as the EU RED and US RFS, there is an opportunity to move beyond the maintenance of ecosystem services (which is the benchmark that is usually applied under current sustainability criteria) to more actively promoting the enhancement of ecosystem services. Sustainability criteria, such as those applied under the RED, are best suited to identifying biofuels that degrade ecosystem services rather than those that enhance them. Life-cycle greenhouse gas calculations can help to promote energy cropping systems that increase carbon stocks, but not those that provide habitat for biodiversity or mitigate soil erosion.

The EU's use promotion of biofuels from cellulosic feedstocks by allowing them to be counted twice against renewable fuel targets demonstrates a potential way forward for promoting biofuels that enhance habitat, soil health, water quality and other ecosystem functions. Additional categories of fuels could be created that are eligible for different multipliers based on the ecosystem services they provide (e.g. fuels that enhance soil health could count for four times their energy content). A similar approach could also be applied to renewable electricity obligation schemes, such as the UK's Renewables Obligation (RO). The RO already has several different multiplier rates or "bands", but these are currently based on the development status of each technology rather than the degree to which ecosystem services are enhanced. For countries with feed-in tariffs, it is relatively simple to assign different rates to different production systems, as is demonstrated by the German bonuses for landscape preservation shown in Table 4.

An alternative to the use of banding and feed-in tariffs to promote ecosystem service provision is the increased use of sub-mandates. For example, the US RFS could be modified to incorporate a sub-mandate for "ecosystem fuels" alongside its current sub-mandate for "advanced fuels". To qualify as an ecosystem fuel, feedstocks would need to be produced in a manner that enhances target ecosystem services, such as switchgrass cropping that provides habitat for biodiversity and reduces soil erosion (Hartman et al., 2011). The EU RED could also be modified to incorporate an "ecosystem fuel" category for which biofuels would only be eligible if they enhanced specified ecosystem services. Sub-mandates or banding could also be applied to mandates for renewable heat supply, although these are less widespread than mandates for transport fuels and electricity and many such schemes are focused on solar water heating rather than bioenergy (REN21, 2016).

Approaches involving sub-mandates, banding and feed-in tariffs all present risks that would need to be managed. Sub-mandates restrict a fuel supplier's flexibility of fuel choice and may result in targets being unmet for certain fuel categories, as has occurred with advanced biofuels in the US due to a lack of available supplies (Environmental Protection Agency, 2013). Banding creates the risk that certain energy types will be over-supplied or under-supplied. For example, where banding is used in Italy, the market regulator is tasked with buying excess certificates to maintain the desired level of renewable generation (Gürkan and Langestraat, 2014). There are also risks around feed-in tariffs, as too low a tariff can result in minimal uptake, while too high a tariff can lead to excessive costs and future policy changes that create uncertainty for investors (White et al., 2013).

Where grants, loans or tax breaks are used to promote energy crops, it is possible to structure these policy instruments to preferentially support energy crops that enhance ecosystem services such as soil protection or habitat provision. The social fuel label employed under Brazil's biodiesel scheme demonstrates how tax concessions can be structured to preference biofuels from particular sources (Barros, 2014). While the objective behind the present tax concession rates is socio-economic in nature, a similar model could be used to promote energy crops that provide ecosystem services relating to soils, water and biodiversity.

In the case of grants for new bioenergy facilities or government payments for the supply of renewable energy, it may be possible to structure tendering or auction schemes to preference certain forms of renewable energy (e.g. energy crops that offer ecosystem services such as soil protection or habitat provision). REN21 (2016) highlights auctions as a growing area of renewable energy policy, with Brazil, South Africa and Peru holding bioenergy auctions in 2015. Some auctions already employ indices that consider factors such as local economic benefits and a company's track record alongside the amount of renewable energy (Azuela et al., 2014) and it may be possible produce more elaborate indices that also incorporate ecosystem service provision. Under such an approach, the contribution that an energy supply system makes to specified ecosystem services would be weighed up alongside other criteria such as the amount of energy provided, the number of jobs created and the likelihood of successful project delivery. The final score for each bidder could then be compared to the price requested to determine the most cost-effective bids.

While many bioenergy support programs are aimed at energy distributors, fuel processors or electricity generators, consideration also needs to be given to policies aimed at the landholder level. Brazil provides notable examples of energy cropping being promoted amongst certain landholder groups or on certain land types through means other than direct payments. For example, increased security of land tenure has been a key element of Brazil's Sustainable Oil Palm Production Program (Villela et al., 2014) and favourable terms for agricultural credit have been used to encourage smallholders to plant oil palm on degraded land rather than clearing forests (Englund et al., 2015). Furthermore, Brazil's attempts to encourage smallholder production of biodiesel through tax breaks for fuel companies under the PNPB had limited success until the state-owned oil company Petrobrás became actively involved in providing seeds, working with smallholders to improve technical and organizational capabilities and partnering with local social movements to ensure fairness in supply contracts (Lima, 2012). These schemes demonstrate how incentives targeted at the landholder level could be used to preferentially promote energy cropping systems that enhance supporting and cultural ecosystem services.

The examples given here demonstrate the wide range of bioenergy and related policies that could be modified to preferentially support energy crops that enhance ecosystem services. However, there is also a need to think strategically across bioenergy support policies within each jurisdiction to ensure that the synergies between the various policies are maximised. Table 5 provides an example of how this could done for a single country (Australia) using the same 15 policy instrument types listed in Table 2.

In Australia’s case, mandates for renewable electricity at the national level and for transport fuels in two states present opportunities for sub-mandates or banding to be used to preference feedstocks that enhance selected ecosystem services. Fuel excise rates could also be varied to reinforce the incentive to use preferred biofuel feedstocks. While energy crops that sequester carbon can earn payments under the national Emissions Reduction Fund, eligibility rules could be tailored to preference energy crops that also provide other ecosystem services, such as soil protection or water filtration. Tendering and public investment processes could be modified through the use of auctions and ecosystem service indices. Some policy options that are currently lacking for bioenergy in Australia, such as feed-in tariffs and renewable heat mandates, could also be introduced with higher incentives for energy crops that promote specified ecosystem services.