The Economic and Social Review, Vol. 48, No. 2, Summer, 2017, pp. 207-229

If Opportunity Doesn't Knock, Build a Door: Reflecting on a Bioeconomy Policy Agenda for Ireland

Laura Anne Devaney*
Teagasc Food Research Centre, Dublin

Maeve Henchion
Teagasc Food Research Centre, Dublin

Abstract: The development of the bioeconomy offers an alternative **economic** mode of growth whereby renewable biological resources are transformed to meet food, feed, fuel and fibre needs. Ireland however lacks a cohesive bioeconomy policy to guide this development. Drawing on a strategic analysis of the resource base in Ireland, this paper sets the scene for the development of the Irish bioeconomy. A number of case study opportunities are outlined, followed by a critical analysis of Irish bioeconomy-related policy. The analysis culminates in a bioeconomy policy illustration that highlights the number of competing interests in the bioeconomy arena, alongside the wider **governance** context that will influence the development of a comprehensive national bioeconomy policy.

I INTRODUCTION

Escalating environmental, social and economic sustainability challenges present a rallying call to change how society produces, processes and consumes food, feed, fibre and materials (SCAR, 2015). Global challenges relating to climate change, biodiversity loss, soil degradation, deforestation, fossil fuel limitations and food and water security persist, compounded by growing populations, increased urbanisation, a rising middle class and economic recession (UNEP, 2012). Patterns of production and consumption are far from sustainable in their current

Acknowledgments: The authors acknowledge the financial support of the Irish Department of Agriculture, Food and Marine for funding through their Stimulus Fund for the project entitled "A Bioeconomy for Ireland – An evaluation of development opportunities, policies and initiatives shaping Ireland's transformation to a sustainable low carbon bioeconomy": Project reference no: 14/SF/857.

* Email: laura.devaney@teagasc.ie / maeve.henchion@teagasc.ie

configuration and require urgent alternatives for future resource security and sustained livelihoods. Moreover, there is a need to seek out new economic growth models that move beyond fossil-based raw materials and petrochemical technologies. The bioeconomy has emerged as one potential alternative, promising to meet societal needs in a more environmentally sustainable manner (McCormick and Kautto, 2013; Socaciu, 2014). As defined by EC (2012, p9), the bioeconomy: "Encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, biobased products and bioenergy".

Rather than returning to the biobased society of pre-industrial times, the application of innovative and novel technologies in the bioeconomy processes what society needs from nature in a more reliable and efficient manner. The bioeconomy thus hinges on the successful interaction of biological resources across multiple natural resource sectors including agriculture, marine and forestry as well as innovation and technology development in energy, chemical, food and biotechnology industries (EC, 2014b). It is a concept that is gaining traction across policy and academic arenas, with novel market opportunities for biobased products only beginning to be exploited worldwide (Babu *et al*., 2013; McCormick and Kautto, 2013). Ireland is particularly well placed to capitalise on these opportunities given its abundant natural resource base, productive soils, thriving oceans, high biomass growth rates, well-established research network and competitive agri-food industry (Fischer *et al*., 2000; Hynes and Hennessy, 2012; O'Donoghue and Hennessy, 2015). How bioeconomy opportunities might develop and be supported in an Irish policy context forms the focus of this paper.

As a result of its broad focus on renewable biological resources, the bioeconomy is particularly complex from a policy perspective. Its development will be influenced by a number of policy arenas including specific sectoral policies across agriculture, food, marine, forestry and energy sectors, cross-sectoral waste, sustainability and innovation polices and multi-level economic, social and environmental policies, among others. Development of one cohesive national bioeconomy policy will thus require government inter-departmental agreement on a variety of issues as well as wide-ranging agreement across a number of stakeholder groups. Indeed, by nature of its broad remit and impact, bioeconomy development will require input from more than just governmental actors alone. Shifting from a government to governance approach (Stoker, 1998; Hooghe and Marks, 2003; Roberts, 2011) will thus be essential for successful bioeconomy development, incorporating the multiple voices and influences involved in its implementation and reallocating "authority upward, downward and sideways from central state" (Hooghe and Marks, 2003, p233). Economic and environmental trade-offs and conflicts are unavoidable in this bioeconomy context, as decisions are made regarding the most efficient and fair use of biological resources across food, feed,

fuel and fibre needs (Mahro and Timm, 2007; McCormick and Kautto, 2013; Lewandoski, 2015).

In response, political attention concerning the bioeconomy has been connected with ideas of the circular economy (Bonciu, 2014; Ellen MacArthur Foundation, 2015) and the cascading principle of sustainable biomass use (SCAR, 2015). The former concept focuses on rebuilding capital and enhancing the flow of goods including the utilisation of waste, by-product and co-product streams from production and processing systems. The cascading principle, by comparison, prescribes that biomass is used sequentially as often as possible to create materials (for example, higher value pharmaceutical, food, feed, plastics and chemicals) before the creation of heat and energy (SCAR, 2015). Incorporating these principles helps to enhance sustainability in the bioeconomy and mitigate food-feed-fuel land use conflicts as biowastes are incorporated as inputs (Mahro and Timm, 2007). Such progressions also shift the bioeconomy further away from bioenergy opportunities of lower economic value, to instead focus on biochemical, biopolymers and bioplastics that hold more currency today (Ragauskas, *et al*. 2006; Babu *et al*., 2013). These ideas are echoed by SCAR (2015, p15) whereby "food first" is also denoted as a founding principle for bioeconomy development, emphasising that food security must be secured before any material output is considered. Pushes for circularity, a cascading approach, sustainable yields and diverse production systems are also prioritised as bioeconomy principles by SCAR (2015).

As a result, processes of bargaining, deliberation and compromise-seeking in a supportive governance approach (Roberts, 2011) will be paramount to future bioeconomy success to implement commonly agreed principles and overcome issues of competition between biomass uses. A precursor to realising national bioeconomy opportunities is thus an aligned, consistent policy context in which the compromises made are acceptable to all stakeholders involved. This should be feasible given the plethora of opportunities available, however it will first require an analysis of the policies that influence, or are impacted by, developments in the bioeconomy. As Hilgartner (2007, p382) states: "To guide policymaking, analysis must map the present state of the bioeconomy, anticipate its evolution…and pinpoint any key issues".

This paper aims to commence this analysis from an Irish policy perspective. It emerges from a situational and strategic analysis of the biological resource base in Ireland, drawing on published reports, academic literature, secondary data sources and key informant interviews. This preliminary investigation involved a detailed exploration of five specific Irish bioeconomy sub-sectors (agriculture, food, forestry, marine and bioenergy) and, in particular, the volume, types and current uses of related biological resources. Ireland's strategic capabilities in the bioeconomy were also assessed using strategic business planning tools such as SWOT analysis (Ghazinoory *et al*., 2011) to identify the strengths, weaknesses, opportunities and threats associated with each sub-sector and the bioeconomy as a

whole. Findings of the analysis were "sense checked" through confrontation by researchers from a diverse range of disciplines that are active in various aspects of the bioeconomy. A variety of case study opportunities emerged from this analysis; three of which are explored in this paper with the aim of setting the scene for the future Irish bioeconomy. Highlighting potential future opportunities, the selection of case studies should not be interpreted as a blueprint for Irish bioeconomy development nor is it intended to simplify the range of opportunities available. Rather, the purpose of this paper is to highlight potential growth opportunities to exploit and stimulate further discussion on a national bioeconomy policy for Ireland; something that is lacking direction at present.

II IRELAND AND THE BIOECONOMY: RESOURCE POTENTIAL, INNOVATION CAPACITY AND ECONOMIC PROMISE

The abundant natural terrestrial and maritime resource base evident in Ireland forms an important and unique foundation for the development of the Irish bioeconomy, along with strengths such as a thriving agriculture sector (Hynes and Hennessy, 2012) and natural forestry advantages with respect to tree growth rates (Duesberg *et al*., 2014). Indeed, despite a high proportion of Irish farmland categorised as "disadvantaged" areas under the Common Agricultural Policy (Matthews, 2000), Ireland is denoted as "the envy of the world" with its "abundant fertile land, clean inland waterways, and miles of coastline" (Government of Ireland, 2012). Producing high quality outputs (Hynes and Hennessy, 2012), additional competitive advantages are associated with the island's close proximity to the Single European Market of approximately 500 million people (Eurostat, 2015).

Much of the terrestrial advantage in Ireland stems from the significantly long growing season resulting from the temperate climate and fertile soils, with potential for growth up to 10 months of the year (Brereton, 1995). Indeed, the long growing season and rainfall patterns generate one of the highest biomass growth rates of any country globally (Fischer *et al*., 2000). From a marine perspective, Ireland's natural coastline and continental shelf represents another distinct physical advantage. According to Forfás (2009), Ireland's underwater seabed is ten times the area of its landmass, standing at approximately 865,000km^2, making it one of the largest seabed territories in Europe (Marine Institute, 2015).

Meanwhile, levels of innovation capacity in Ireland further bolster bioeconomy potential nationally, with a growing number of dynamic chemical, pharmaceutical, energy and material industries as well as a well-respected and innovative food industry. Indeed, Lin *et al*. (2010, p. 161) characterise Ireland as a "major regional innovator", facilitated by a dedicated bottom-up approach that creates a supportive environment for firm-level R&D and attracts significant foreign direct investment

assisting local level learning. As a result, the Irish agri-food sector is denoted as the fifth most innovative in the European Union (DAFM, 2015). Renowned research capabilities further this innovation potential across an internationally recognised university network, a variety of institutes of technology and dedicated research organisations. Moreover, the national research strategy highlights research priorities in bioeconomy-related areas such as functional foods, sustainable food production and processing, marine renewable energy, processing technologies and novel materials (Forfás, 2011). For instance, the Department of Agriculture Food and the Marine (DAFM) awarded approximately €100 million to agri-food, marine and forestry research between 2010 and 2014 (DAFM, 2014; 2015); evidence of the significant political commitment to developing biobased sectors in the country.

To underpin research commercialisation, a number of industry facing programmes also operate, further enhancing national innovation potential. Enterprise Ireland, for example, operates a number of Technology Centres nationwide with dedicated commercialisation funds. Between 2013 and 2014, the organisation supported a total of 35 R&D projects in the food sector, committing in excess of €15 million and leveraging a further €60 million in total R&D investment (DAFM, 2014). These projects focused on new product and process development; key elements of value addition promoted by the bioeconomy ethos. Public-private partnerships are an additional important vehicle in this space. For instance, Food for Health Ireland (FHI) links researchers with industry partners to collaboratively develop, manufacture and market functional food ingredients.

Finally, to enhance innovation adoption, several programmes operate that focus on the transfer of knowledge and technology to farmers and other landowners. For example, Teagasc, the Irish Agriculture and Food Development Authority, provides a number of advisory services and educational programmes supported by open days on research farms, model farms and green-field site developments, providing advice to farm households on emerging farm practices, diversifying output and showcasing new technologies (Teagasc, 2016). Such measures aim to bridge gaps between research and practice and mitigate persisting concerns regarding the absorptive capacity of farmers with regard to technology adoption (Howley *et al*., 2012; McDonald *et al*., 2015).

From an economic perspective, the need to make the bioeconomy measurable has been highlighted by Hilgartner (2007). For Hilgartner (2007, p382) advancing the bioeconomy involves viewing it clearly as "a set of technological and economic activities", reflecting the economic output emphasis similarly reported by McCormick and Kautto (2013) in their review of bioeconomy definitions across policy frameworks worldwide. In their discussion of food and water in the global bioeconomy, Rosegrant *et al*. (2013, p139) similarly focus on the economic benefits offered by the bioeconomy, defining it as "economic growth driven by the development of renewable biological resources and biotechnologies to produce

sustainable products, employment and income". The economic benefits of the bioeconomy must thus be measured and recognised when considering its future development and implementation.

Indeed, using macro-economic indicators, research has already quantified benefits that accrue to Ireland as a result of activity in sub-sectors of the bioeconomy. Analysis undertaken by Riordan (2012), for example, in relation to the agri-food sector found that it contributes proportionately higher net foreign earnings than might be expected by export levels alone. This is due to the relatively low import requirement per unit of output as a result of utilising domestic natural resources, as well as high levels of indigenous ownership and thus lower levels of profit repatriation. Activities in the sector were also found to result in a high local multiplier effect. Extending beyond the agri-food sector, a Bioeconomy Input Output model (BIO) was developed in 2015 to analyse the linkages between agricultural and marine based bioeconomy sectors and the wider Irish economy (Grealis and O'Donoghue, 2015). In this report, the tendency for bioeconomy sectors to derive many of their inputs nationally is emphasised, resulting in a higher impact in terms of national and regional development compared to other sectors that rely on imported inputs (for example, as evident in other chemical and material manufacturing sectors). Furthermore, these sectors employ relatively more people per unit of output, further supporting employment in rural regions. The higher levels of national sourcing and employment per unit of output means that "when these sectors increase their sales and in particular their exports, they generate a greater impact on the economy" (Grealis and O'Donoghue, 2015, p10). The model also highlights the indirect employment that results from bioeconomy activity. For instance, in relation to the marine sector alone, the BIO model found that achieving sectoral targets set in the national marine strategy would result in a direct impact of €3.3 billion, with an additional indirect effect of €2.7 billion for the wider economy. The economic potential inherent in bioeconomy development thus holds significant promise for Ireland, warranting further investigation of potential new opportunities and value chains for development. With the aim of stimulating discussion on the potential growth opportunities available and need for a strong and cohesive national bioeconomy policy for Ireland, three distinct case study opportunities will now be highlighted.

III OPPORTUNITIES IN THE BIOECONOMY

In keeping with Stake (1995), the selected case studies are instrumental in nature, playing a supportive role in facilitating understanding of the wider bioeconomy, rather than representing decisive outcomes or pathways for development. Thus, the case study approach can stimulate discussion and thinking regarding the potential

bioeconomy opportunities available and the challenges associated with their exploitation. As with any case study methodology (Yin, 2009), the opportunities outlined are grounded in a specific geographic and temporal context and merit further analysis to establish their future feasibility. Multiple sources of data contribute to this analysis including detailed literature and policy reviews, input from key informant interviews, an examination of international best practice, and a strategic analysis of Ireland's capabilities. In keeping with Baxter and Jack (2008, p554): "Each data source is one piece of the 'puzzle', with each piece contributing to the researcher's understanding of the whole phenomenon. This convergence adds strength to the findings as the various strands of data are braided together to promote a greater understanding of the case".

In this way, the case studies are exploratory in nature; an appropriate approach given that the situation under review has no single or clear set of outcomes (Baxter and Jack, 2008; Yin, 2009). Given the importance of establishing boundaries within case study methodologies (Baxter and Jack, 2008), the below cases are selected based on a desire to achieve a breadth of understanding on the bioeconomy issue and the range of value chain options potentially available, as opposed to achieving significant depth. A more in-depth analysis, including regarding the technical, economic and environmental feasibility of the value chains (Jordan *et al*., 2007), will form the focus of later research phases and subsequently be published.

With this perspective in mind, three diverse case studies are outlined below. These include opportunities to utilise organic waste from the agricultural sector, harness the marine potential that exists off the coast of Ireland and process biomass originating from semi-natural habitats. The case studies capture a sense of the diversity that will be required for the development of a resilient and innovative bioeconomy and associated policy framework (SCAR, 2015). They also represent areas that have been awarded funding for research, development and innovation (RDI) in recent years. As such, the case studies are spread across bioeconomy sub-sectors and as a result face different policy contexts, infrastructural conditions and technological challenges, highlighting additional aspects for consideration in developing one over-arching national bioeconomy policy.

Case Study 1 – Non-Food Opportunities in the Agricultural Sector

Developing opportunities from current waste streams is essential for a sustainable bioeconomy. As detailed in the House of Lords (2014, p13) report: "Waste biorefining has the potential to completely eliminate the competition for land that is inherent in the use of most other feedstocks, such as food crops. This may result in waste becoming the most sustainable feedstock of all".

In this regard, a number of production and processing side streams, by-products and co-products demonstrate potential for further value addition, transforming waste "from a problem into a resource" (House of Lords, 2014, p13), closing the

resource loop and rebuilding capital in keeping with a circular bioeconomy vision (Bonciu, 2014; Ellen MacArthur Foundation, 2015).

According to Bonsall (2015), the Irish agricultural sector in particular generates a number of organic wastes that are currently underutilised and could underpin the development of the Irish bioeconomy. This includes a variety of manures, slurries, straw, husks and spent grain that may be further processed using biorefining techniques to create a range of biochemicals, biomaterials and bioenergy. For example, Bonsall (2015) estimates the generation of 2 million dry matter tonnes (DMT) of animal slurry in Ireland every year, 1 million DMT of straw, stover and husks and 150,000 DMT of spent grain; elements that are currently used for land spreading or as low value animal bedding or feed. Challenging the definition of the term 'waste' in the future bioeconomy (Mahro and Timm, 2007), higher value opportunities exist for such by- and co-products to extract economically valuable molecules and elements to act as platform chemicals for further product conversions. Lower down the value chain and in keeping with the cascading approach, residual animal and crop waste streams could also be used to produce bioenergy through anaerobic digestion (ADAS, 2008). Such ideas offer both potential waste management solutions for Irish farmers as well as economic opportunities to create value and diversify income. Furthermore, the valuable nutrients from slurry (including nitrogen, phosphorus and potassium) may still be recovered in the anaerobic digestion process and spread on the land to improve soil fertility (subject to legislative controls). Rich in nitrogen, animal derived wastes however must be combined with carbon rich sources to achieve optimum biogas production (e.g. grass derivatives) (ADAS, 2008). The resulting biogas may then be used to generate electricity, heat or vehicle fuel. Preliminary opportunities and challenges of developing bioeconomy value chains from agricultural waste are outlined in Table 1, in comparison to the other case study opportunities presented below.

Case Study 2 – Harnessing Marine Potential

Under the United Nations Convention on the Law of the Sea, Ireland has sovereign rights to explore and develop the natural resources associated with its 865,000km^2 of seabed territory. Significant potential thus exists for the development of future food, feed, fuel and material outputs from this abundant resource base. Brennan and Gormley (1999) and Hayes and Fagan (2014) for example, highlight a number of underutilised marine species in Ireland, such as Orange Roughy and Boarfish. The novel protein compounds associated with these species are particularly noteworthy given growing protein demand worldwide and the need to source more sustainable protein than currently obtained through livestock production (Hayes and Fagan, 2014; Blanco *et al*., 2015). Fish and marine protein represent a suitable alternative, representing an easily digestible and nutritionally superior protein source compared

to plants, often hosting a better balance of essential amino acids (García-Vaquero and Hayes, 2016). Further value addition is also possible, with developments in processing technology enabling the extraction of functional food compounds and bioactives from underutilised, or even discarded, marine resources (Hayes *et al*., 2008; Blanco *et al*. 2015). For example, extractions from seaweed and algae may be harnessed for their techno-functional attributes (including foaming, gelation and emulsification in food processing industries) as well as for their purported human and animal health benefits (including the extraction of antioxidants as functional food ingredients) (Hamed *et al*., 2015; García-Vaquero and Hayes, 2016; Sweeney and O'Doherty, 2016). Representing an additional waste management solution, Rustad *et al*. (2011) similarly highlight potential for the preparation of different by-product fractions from the marine sector given that up to 75 per cent of catch can end up as waste due to postharvest processes. Further processing of fish blood, protein fractions, marine lipids, omega-3 fatty acids and bioactive compounds with nutraceutical potential are especially noted, compared to low-profit uses such as fish meal (Rustad *et al*., 2011). Extracting this value will become increasingly important with the introduction of a zero-discard policy in the EU that will result in new landing obligations for the marine sector (Blanco *et al*., 2015; DAFM, 2015).

Exoskeletons of crustaceans such as crab, lobster and shrimp shells represent an additional noteworthy source of a number of bioactive compounds. Meat accounts for just 40 per cent of a crab's mass, with the remainder (predominantly shell) often dumped in landfill or at sea (Yan and Chen, 2015). The extraction of chitin from such sources has gained particular attention of late as a result of its nitrogen-containing properties and resulting wide range of uses across pharmaceutical, medical, bioremediation, cosmeceutical and chemical industries (Hayes *et al*., 2008). There is potential for value addition in this waste arena in Ireland with benefits for both the economy and the environment if extracted in a sustainable manner. Indeed, the presence of 23,807 tonnes of shellfish landed by Irish vessels in 2013 (DAFM, 2015) suggests a viable and currently underutilised resource base. The industrial production of nitrogen compounds nonetheless requires further R&D before exploitation given the potential negative environmental impacts that may occur during extraction phases (typically a carbon, water, chemical and energy intensive process). Yan and Chen (2015) however do not envisage this technical drawback to significantly hamper progress in the marine bioeconomy arena, with much R&D already underway to overcome these barriers (including the possible use of bacteria or fermentation methods to carry out extraction processes).

According to Hamed *et al*. (2015, p1), "marine organisms constitute nearly half of the worldwide biodiversity; thus, oceans and sea present a vast resource for new substances and…beneficial natural molecules". Through new extraction methods and product development, these molecules may be used to prevent, treat and even cure a range of cardiovascular diseases, inflammatory conditions and cancers

(Hamed *et al*., 2015). Providing alternatives to low value feed uses, potential to improve consumer health, minimise waste and develop renewable products, opportunities in the marine sector thus need to be carefully examined when considering the future of the Irish bioeconomy. Opportunities and challenges associated with realising this potential are discussed in Table 1.

Case Study 3 – Optimising Biomass from Semi-Natural Habitats

The final potential opportunity area outlined in this paper draws inspiration from international best practice concerning the use of wild, pest and semi-natural species to create high value bioeconomy outputs. As noted by Gunter Pauli in a series of public lectures in Namibia: "The secret to economic emancipation lies in nations using every single resource at their disposal, especially those that are free" (Abankwah, 2014). The establishment of the Matrica complex in Sardinia provides particular inspiration, functioning as a green chemistry plant for the development of bioplastics in Italy. The plant utilises local thistle weeds as an input in its production process, converting the natural vegetable oils into a range of chemical intermediates and bioplastics (for example, extender oils for the rubber and tyre industry, lubricants and cosmetic oils) (Vogt, 2014). Providing economic, social and environmental benefits for the local community, at full capacity the plant will produce up to 70,000 tonnes of bioproducts annually, employing almost 700 people and drawing on local raw materials that commonly grow year-round on poor Sardinian farmland (Vogt, 2014).

There is opportunity to explore uses for similar pest and semi-natural species in an Irish bioeconomy context. Smyth (2015), for instance, points to the potential positive attributes presented by the broadleaf dock, a common weed found throughout Ireland. Compared to marine resources, Smyth (2015) deems the dock leaf to be easier to extract, with no issues regarding salinity and possessing a high polyphenol content (a beneficial antioxidant). Broadleaf dock is also in abundant supply in Ireland, infesting more than 15 per cent of productive grassland and competes with grass (the principal feedstock in Irish agriculture) for light, nutrients and moisture (DOW, 2015). Extraction of the broadleaf dock for further biorefining could thus add value to an otherwise pest species.

Grass similarly represents another abundant, semi-natural cultivation with potential for further value addition in Ireland (O'Neill at al., 2013). According to ADAS (2008), annual dry matter output from grassland in Ireland ranges from 5,000 kg h^{-1} to 18,000 kg h^{-1}, depending on fertiliser input and soil characteristics. Moving beyond its use as a low cost animal feed, the potential to add further economic value to grass is increasingly recognised in a green biorefining context (Mandl, 2010). Further material, chemical and energy uses exist for both grass fibres (e.g. silica and cellulose) and grass juices (e.g. sugar proteins, colourants, alkaloids and insulin). Indeed, refining of grass can create suitable platform

chemicals for a number of further biochemical applications (Mandl, 2010). This is a common feature of many lignocellulosic feedstocks whereby sugars are released during the biomass fermentation process, producing monomers (ADAS, 2008). The use of different species of grass or grass from non-intensive farmland merits further consideration in the future Irish bioeconomy. Opportunities and challenges associated with developing value chains from semi-natural species are outlined in Table 1 in comparison to the other value chain areas presented.

Table 1: Potential Value Chains For The Irish Bioeconomy: Opportunities and Challenges

Bioeconomy Value Chain	*Benefits*	*Challenges*
Non-food opportunities in the agricultural sector	• Waste management solution • Reducing costs of waste disposal • Diversifying and increasing farmer income • Environmental benefits through the utilisation of waste streams • Production of biochemicals and bioenergy • Creation of public private	• Regulatory issues concerning the definition of waste and permitted uses, e.g. land spreading • Large capital investment required to develop biorefining plants • Fragmented feedstock supply presents implications for location and scale of biorefineries/ anaerobic digesters • Policy alignment needed beyond the agri-food sector to address energy production for domestic and commercial use and the need for infrastructure and appropriate supports to stimulate development • Learning curve for agri-food producers and processors moving outside of the sector
Harnessing marine potential	• Abundant resource base available to Ireland • Zero-discard policy provides additional supply base • Uses across the spectrum including high value pharmaceutical and industrial applications • Waste and environmental management solution	• Regulatory issues concerning the definition of waste and harvesting of seaweed • Significant RDI requirements to continue developing safe and environmentally sound extraction processes • Need for pilot and demonstration projects to translate research into practice

Table 1: Potential Value Chains For The Irish Bioeconomy: Opportunities and Challenges (Contd.)

Bioeconomy Value Chain	*Benefits*	*Challenges*
Harnessing marine potential (contd.)	• Purported health benefits of marine-derived bioactives • Diversifying and increasing fishing community income • Creation of new business models (e.g. co-operatives) to process marine resources • Potential higher consumer acceptance of marine-derived products (e.g. acceptance amongst different religious communities)	• Collection of material in required volume • Developing reliable supply and transporting to relevant facility • Organisational and process innovation required to realise marine opportunities
Optimising biomass from semi-natural habitats	• Abundant resource base • Potential use of pest species (e.g. broadleaf dock) • Simpler extraction methods compared to marine species • Potential high value biochemical applications alongside additional biomaterial and energy uses • Development of quality grade bands for wild and pest species • Mixed feedstock processing to combat issues of seasonality (e.g. potential to combine with organic waste streams)	• Competing land uses in the face of existing public policy • Significant RDI requirements to develop sustainable uses • Capital investment for green biorefineries • Scale and context of biorefineries to compete with prevailing chemical competitors • Collection of material in required volume; potential de-watering of grass to reduce transport costs • Developing a reliable, consistent supply year-round • Accepting market and available buyers • Acceptance by farming community that is focused on increasing output and efficiency gains

Source: ADAS, 2008; Mandl, 2010; Hayes and Fagan, 2014; Blanco *et al.*, 2015; Bonsall, 2015; Hamed *et al.*, 2015.

Overall, the above case studies represent just three of many potential developments across national and international bioeconomy arenas, with new ideas, technologies and product innovations emerging every day that capitalise on renewable biological resources. What the three case studies highlight is the potential

that rests in the Irish resource landscape and the need for bioeconomy opportunities to be explored across numerous biological resource sectors. Challenges to value chain development in these areas remain however, including competing land uses, regulatory restrictions, the potential for negative environmental trade-offs, the need for significant capital and RDI investment, transport logistics and market acceptance and availability. Above all, developing a reliable, consistent and critical mass of biomass supply represents a distinct challenge unique to bioeconomy development. These challenges highlight the need for value chains to be accompanied by appropriate regulatory, technological, infrastructural and research supports to maximise chances of success. A central element of this supportive framework will be the development of one cohesive bioeconomy policy; something that is lacking at present, thus representing a significant constraint in the Irish bioeconomy context.

IV CHALLENGES IN THE BIOECONOMY: POLICY GAPS AND OVERLAPS

While there is significant positivity regarding the development of the bioeconomy, a number of challenges to its development remain. In particular, challenges of coherence exist at a national scale, with a need to ensure sufficient collaboration, communication and consensus across bioeconomy sub-sectors including agriculture, food, forestry, marine, waste and energy. There is a need for synergies and alignment on what the bioeconomy might look like, how it will be regulated, what RDI will be required and what markets will need to be developed to create demand for its outputs. This is essential to ensure a level playing field for bioeconomy stakeholders, assess progress and provide a common set of goals to work towards. Such alignment and direction is also necessary to minimise competition between the generators and users of biomass (for example, so that the food first and cascading use principles are adhered to) (Lewandoski, 2015). From a policy perspective, bioeconomy sub-sectors typically operate in isolation of one another with dedicated national strategies in each arena. For example, in Ireland, DAFM issued "FoodWise 2025" in July 2015, the country's roadmap strategy for the Irish food and agriculture sector (DAFM, 2015a), while in December of the same year, the Department of Communications, Energy and Natural Resources launched an energy white paper mapping "Ireland's Transition to a Low Carbon Energy Future 2015-2030" (DCENR, 2015). While both strategies emphasise the need for Irish food and energy sectors to develop in an environmentally sustainable manner, there is no overlap or cohesion as to how this might be achieved collaboratively or in a complimentary manner as part of a wider bioeconomy (for example, sharing of biomass between sectors, developing mutually beneficial regulations regarding land use, or fostering new working relationships between food

and energy stakeholders). A dedicated national bioeconomy policy is essential to connect up biological resource sectors and existing ideas and innovation for optimum value chain development and governance.

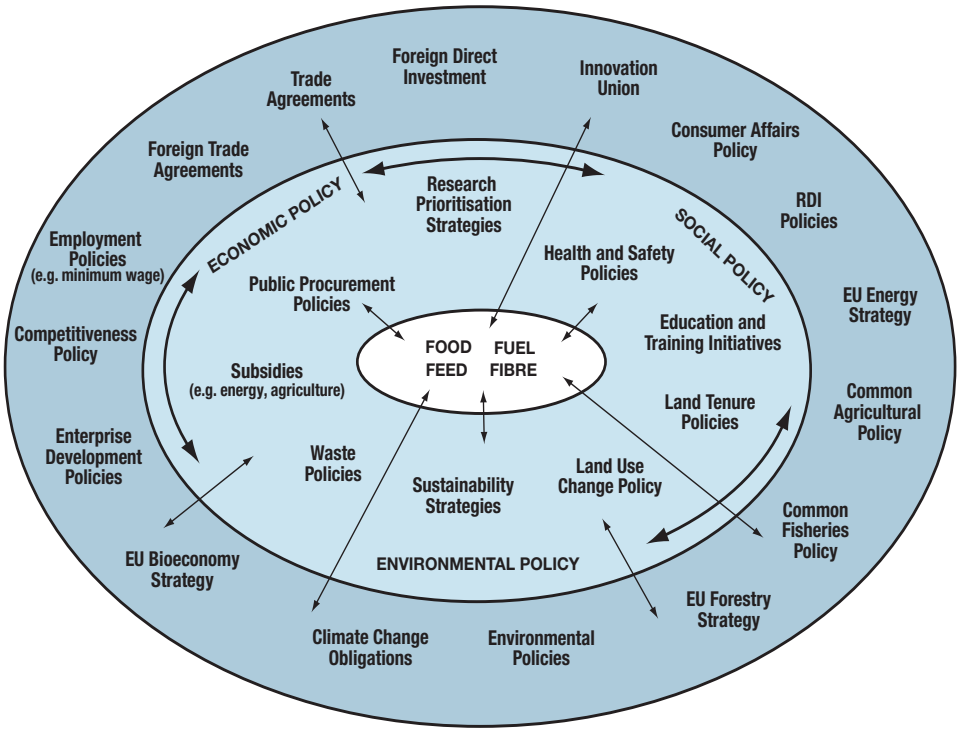
Indeed, the need to move beyond traditional government intervention to include the variety of stakeholders involved in bioeconomy development as part of a wider governance framework is essential to connect up the range of researchers, private companies, representative bodies and environmental NGOs, among others, and reduce competition between sectors (Stoker, 1998; Hooghe and Marks, 2003; Roberts, 2011). Similar to McGloughlin and Sweeney (2012) and their discussion of governance in relation to climate change adaptation in Ireland, the need for both vertical and horizontal integration is essential to not only connect actors across local, regional and national scales (levels of government) but across departments and sectors also (breakdowns within each level). The potential role for joint committees comprising of members across sectors and scales would have obvious merit in helping to formalise this process of cooperation, facilitating and prioritising synergies in the bioeconomy space (McGloughlin and Sweeney, 2012). "Strong political, professional and technical support" will be essential to champion bioeconomy activities just as some local authorities succeeded in championing climate change activities in England and Wales (Allman *et al*., 2004, p271). In practical terms, this includes providing dedicated staffing, budgets and resources alongside appropriate partnerships and the prioritisation of activities across, and within, governance levels (Allman *et al*., 2004).

Similarly, in their assessment of bioeconomy opportunities and trade-offs in Europe, McCormick and Kautto (2013) report a need for increased forms of participatory governance in future development strategies. Deciding exactly who should participate and how will be crucial, from public-private networks to city regions and NGOs to citizen-consumers (McCormick, 2011). Hooghe and Marks (2003) similarly highlight the importance of establishing how multi-level governance should be organised in practice, with the bioeconomy lending itself to forms of task-specific yet flexible modes of governance and jurisdictional organisation. A coherent national policy that draws on domestic strengths and identifies bioeconomy weaknesses would help to identify priority areas for bioeconomy development in Ireland and highlight the stakeholder groups that require engagement for value chain opportunities to be realised. Such a policy would also ensure that appropriate opportunities are supported by additional policy measures (e.g. relating to favourable taxation, public procurement and sustainability and safety criteria). Comprehensive national policies that clarify and establish fruitful cross-sectoral synergies internally are thus the first step in building a more robust, coherent and sustainable global bioeconomy. After all, bioeconomy value chain opportunities, economic growth, job creation and rural development are, and should remain, context specific to maximise the unique resources and distinct challenges that exist worldwide.

Symptomatic of geographical diversities, no one size will fit all however when developing national bioeconomy policies; a point that is increasingly recognised in policy and academic fields (Socaciu, 2014). Indeed, at a meeting of international delegates at the inaugural Global Bioeconomy Summit (GBS) in November 2015, the diversity between nations in terms of resource bases, infrastructure, political systems and historical legacies was widely acknowledged. The subsequent need to develop diverse and differentiated national bioeconomies was thus highlighted (GBS, 2015). A limited number of countries have developed dedicated national bioeconomy strategies to date including the United States, Greenland, Japan, Malaysia, South Africa, Finland, Germany and Iceland (German Bioeconomy Council, 2015). As detailed in the GBS (2015, p5) communiqué however: "Bioeconomy might best be moved forward with a set of diverse strategies adjusted to specific national and regional opportunities".

The question remains as to what this policy should focus on from an Irish perspective (BioBase NWE, 2015). Just as the bioeconomy promises multiple benefits, a national bioeconomy policy must incorporate multiple aims and objectives. Developing this policy will thus not be straightforward in the Irish, or indeed any other national context. Multiple policy arenas must interact and will exert influence on such a national strategy, as detailed in the bioeconomy policy illustration below (Figure 1). In this diagram, bioeconomy aims are influenced by a range of economic, environmental and social policies at local and national scales, as well as a wider range of global and macro-level agreements that address both supply and demand side issues. While not purporting to be exhaustive in terms of all policy arenas that influence bioeconomy policy development, this illustration highlights the complexity involved in creating a national bioeconomy policy and the need for multifaceted negotiations between all involved parties across public, private and civil society spheres and sectoral arenas. This may prove particularly challenging given the number of competing interests and power relations that operate across these spaces promoting alternate agendas. The five bioeconomy principles set out by SCAR (2015) provide some initial guidance to address these potential conflicts, however the implementation of such principles in reality remains challenging. This is particularly the case if the principles run against today's existing market environment (SCAR, 2015). Further, the need to establish value chains that are simultaneously economically, environmentally and socially sustainable is no easy task. Competition will inevitably arise between these sustainability objectives, just as competition will arise between specific sectors and actors (McCormick and Kautto, 2013; Lewandoski, 2015). Such issues further highlight the need for clear policy direction to avoid further food, fuel, feed and fibre debates (Mahro and Timm, 2007) and mitigate any unintended consequences or possible rebound effects associated with developing the bioeconomy.

Figure 1: Irish Bioeconomy Policy Illustration



Promoting further horizontal and task-specific governance between relevant actors (Hooghe and Marks, 2003; McGloughlin and Sweeney, 2012), the establishment of an independent national bioeconomy advisory committee, akin to the German Bioeconomy Council (Bioökonomierat, 2016), may further contribute to Irish bioeconomy policy development. This would allow policymakers to access a range of inter-disciplinary experts to help frame and devise a coherent national strategy. An initial key task for such a group would involve reviewing the existing science and evidence base associated with the national bioeconomy, drawing on international best practice as well as considerations for market development and consumer needs. A second step could then involve highlighting the stakeholders requiring engagement in the Irish bioeconomy, with transparent communication and inclusive collaboration essential to establish a fair, balanced, realistic and ultimately implementable bioeconomy policy. As with the German Bioeconomy Council, an independent Irish Bioeconomy Council could also engage in scientific and political dialogue, publishing position statements and promoting the bioeconomy vision to wider society (Bioökonomierat, 2016). Expertise relaying

the exact quantities of existing biological resources in Ireland will be crucial to identify preliminary opportunities for exploitation, alongside knowledge relating to appropriate transformation technologies and market demand. After all, alongside new and future value chain opportunities, already well-established biosectors and economic markets will need to be integrated into the future bioeconomy vision (Socaciu, 2014). The existing institutional infrastructure governing agri-food, forestry and marine activities will therefore need to be assessed and potentially revised in light of the bioeconomy ambition to avoid any barriers to coordination across sub-sectors. Appropriate policy measures that go beyond mere financial incentives (Duesberg *et al*., 2014) will also be needed to underpin each of these areas spanning supply, demand and RDI dimensions (in keeping with Figure 1). This will be essential to induce behaviour change and overcome any barriers related to diversifying output amongst producers and relevant landowners. Further, taking lessons from the failure to establish high level implementation teams in the context of climate change adaptation (McGloughlin and Sweeney, 2012), stronger legislative teeth will be required for any bioeconomy policy to be effective. An appropriate legal and institutional framework will be essential to grant power and authority to the activities of any national bioeconomy team or council. In this way, any gaps, overlaps or contradictions between policy approaches or competition between natural resource sectors as alluded to in Figure 1 may be mitigated.

Finally, there is a need to develop market demand and public acceptance of biobased goods if the ultimate outputs of the future bioeconomy are to succeed. As stated by the German Presidency (2007, p5) "science needs the support of society" with a distinct aspiration highlighted for "a well-informed public, aware of the opportunities and risks of biotechnology". Lessons from previous consumer scares and technology rejections (for example, concerning genetic modification) must be considered to ensure that consumer acceptance is achieved in the bioeconomy, overcoming any ethical or legal concerns. The public will thus need to be included in bioeconomy decision-making processes, companies must remain transparent regarding their methods of production and processing and the balanced, transparent and feasible regulation of any bioeconomy technologies must be ensured to foster a culture of acceptance (German Presidency, 2007). Policy measures to stimulate market and consumer demand through, for example, public procurement initiatives, will also be essential to develop markets for new biobased products.

Overall, requirements for a successful bioeconomy include not only technological development and supply side management, but holistic programmes and policies for market development, consumer trust-building and regulation. The case studies outlined in this paper serve as three starting points for such conversations, opening up dialogue regarding how best Ireland can develop within a bioeconomy framework.

V CONCLUSION

As Hilgartner (2007, p382) states, policy development with regard to the bioeconomy has the power "to help or hinder its growth". As evident in this paper, developing the bioeconomy is particularly complex from a policy perspective. The bioeconomy has a very broad focus, is influenced by a number of policy areas and actors and possesses inherent trade-offs and resource use conflicts. While designing all policy is complex, such characteristics make the bioeconomy especially difficult from a political perspective. It will demand inter-departmental and sectoral agreement and compromise on a number of supply, demand and technological issues. Its development needs to balance food, feed, fuel, fibre debates, productivist discourses with regional and rural development processes, and supply with demand side considerations. In addition, a successful bioeconomy must satisfy a diverse range of stakeholder groups from producer to consumer levels. A strong national bioeconomy policy is thus an essential first step in addressing these issues and establishing common bioeconomy principles, goals and governance objectives.

The bioeconomy is not inherently sustainable (GBS, 2015), and any endeavour to develop it must ensure that its environmental purpose is not self-defeating. Similarly, wider economic issues such as the reliance on direct payments and subsidies in multiple biological resource sectors (Jordan *et al*., 2007; Hynes and Hennessy, 2012) must also be included in any assessment of the economic viability of future opportunities. This is particularly true in Ireland where, at an aggregate level in 2010, subsidies to agriculture, fisheries and food amounted to approximately €1.7 billion or almost 70 per cent of sectoral income (Hynes and Hennessy, 2012). While global and supranational strategies exist, calls for dedicated and diverse national strategies are increasing to account for local bioeconomy nuances, strengths and weaknesses (Socaciu, 2014). As demonstrated in this paper however, the development of such a national strategy in an Irish, or indeed any other national, context will require multiple forms of collaboration, negotiation, expertise and input across a range of producers, processors, researchers, policymakers, civil society actors and consumers. The potential for a dedicated and independent Irish Bioeconomy Council to coordinate such efforts should be assessed.

Furthermore, moving from productivist discourses, the consumption dimension must not be overlooked in any quest to pursue a sustainable future. It is vital that bioeconomy efforts do not simply evolve to create more material items for quick use and disposal. Instead, in keeping with Patari *et al*. (2015), as global sustainability agendas continue to drive changes in markets worldwide, there is potential for a total paradigm shift towards a more environmentally sound bioeconomy that incorporates not just "a new manufacturing paradigm" (Ragauskas *et al*., 2006, p484) but consideration for human well-being and health alongside wider technological change. Socaciu (2014, p1) adopts a similar holistic and

optimistic vision, ambitiously deeming the bioeconomy "a vision for the future society", bringing about a better quality of life. In this way, if executed coherently, bioeconomy development in Ireland may simultaneously tackle a number of social and economic challenges pertaining to economic recession, unemployment, declining rural communities, resource mismanagement and environmental degradation (Hilgartner, 2007; McCormick and Kautto, 2013; Socaciu, 2014). It offers potential to create economically valuable commercial and market opportunities, all the while helping society to "live well, within the planet's ecological limits" (EC, 2014a, p1). Thus, with potential to align sustainability agendas from local to global scales, the need for further research, dialogue and policy action in the Irish bioeconomy space remains. This paper serves as a starting point for such conversations with practical suggestions of importance from a policy perspective, alongside potential case study opportunities that warrant further investigation. While the bioeconomy is not a silver bullet to eliminating societal challenges, the development of appropriate national bioeconomic opportunities represents one important and necessary step towards a more sustainable future.

REFERENCES

Abankwah, C. R., 2014. "A Dollar For Your Thistle", *Windhoek Observer* [Online] Available at: http://observer24.com.na/business/3421-a-dollar-for-your-thistle (accessed: 6/1/16).

ADAS, 2008. "A Study of Bio-refining Opportunities in Ireland", A Report prepared for Enterprise Ireland, ADAS UK Ltd.

Allman, L., P. Fleming and A. Wallace 2004. "The Progress of English and Welsh Local Authorities in Addressing Climate Change", *Local Environment*, Vol. 9, pp. 271-283.

Babu, R. P., K. O'Connor and R. Seeram, 2013. "Current Progress on Bio-Based Polymers and Their Future Trends", *Progress in Biomaterials,* Vol.2, No.8, pp.1-16.

Baxter, P. and S. Jack, 2008. "Qualitative case Study Methodology: Study Design and Implementation for Novice Researchers", *The Qualitative Report*, Vol. 13, No. 4, pp. 544-559.

Biobase NWE, 2015. "Bioeconomy Factsheet – Ireland, Interreg Bio Base North West Europe" [Online] Available at: www.nnfcc.co.uk/publications/view?sectorKey=all-industries&b_start:int=40&typeKey=factsheets-newsletters&yearKey=all-time (accessed: 30/3/16).

Bioökonomierat, 2016. "What is the Bioeconomy Council?" [Online] Available at: http://biooekonomierat.de/en/bioeconomy-council/ (accessed: 6/1/16).

Blanco, M., C. G. Sotelo and R.I. Pérez-Martín, 2015. 'Hydrolysis as a Valorization Strategy for Unused Marine Food Biomass: Boarfish and Small-Spotted Catshark Discards and By-Products', *Journal of Food Biochemistry*, Vol. 39, No. 4, pp. 368-376.

Bonciu, F. I., 2014. "The European Economy: From a Linear to a Circular Economy. *Romanian Journal of European Affairs,* Vol. 14, No. 4, pp. 1-14.

Bonsall, B., 2015. "Agriculture as a Supply Chain for New Bio-chemical and Bio-material Opportunities" [Online], Available at: http://www.teagasc.ie/publications/2015/3714/index.asp (accessed: 7/1/16).

Brennan, M. H. and T. R. Gormley, 1999. "The Quality of Under-Utilised Deep-Water Fish Species", *Teagasc Final Report*, Project Armis No. 4560 [Online] Available at: http://t-stor.teagasc.ie/bitstream/11019/107/1/Report%2022.pdf (accessed: 31/3/16).

Brereton, A. J., 1995. "Regional and Year to Year Variation In Production" in Jeffrey, D. W., M. B. Jones, and J. H. McAdam (eds.) *Irish Grasslands – Their Biology and Management*, Dublin: Royal Irish Academy, pp. 12-22.

DAFM, 2014. "Progress on Food Harvest 2020 Recommendations" August 2014, *Department of Agriculture, Food and the Marine* [Online], Available at: https://www.agriculture.gov.ie/media/migration/agri-foodindustry/foodharvest2020/Milestones201415ArtFINALLayout1170914.pdf (accessed: 6/1/16).

DAFM, 2015. "Annual Review and Outlook for Agriculture, Food and the Marine, *Department of Agriculture, Food and the Marine* [Online], Available at: http://www.agriculture.gov.ie/media/migration/publications/2015/AROFinalVersion2015Amended210915.pdf (accessed: 6/1/16).

DAFM, 2015a. "Food Wise 2025", *Department of Agriculture, Food and the Marine* [Online], Available at: http://www.agriculture.gov.ie/foodwise2025/ (accessed 6/1/16).

DCENR, 2015. "Ireland's Transition to a Low Carbon Energy Future 2015-2030", *Department of Communications, Energy and Natural Resources* [Online] Available at: http://www.dcenr.gov.ie/energy/SiteCollectionDocuments/Energy-Initiatives/Energy%20White%20Paper%20-%20Dec%202015.pdf (accessed: 6/1/16).

DOW, 2015. "Docks", *Dow Agro Sciences* [Online] Available at: http://www.dowagro.com/en-ie/ireland/grassland/weeds/docks (accessed: 6/1/16).

Duesberg, S., V. Upton, D. O'Connor and Á. Ní Dhubháin, 2014. "Factors Influencing Irish Farmers' Afforestation Intention", *Forest Policy and Economics*, Vol. 39, pp. 13-20.

European Commission, 2012. "Innovating for Sustainable Growth: A Bioeconomy for Europe", *European Commission,* COM(2012), 60 final.

European Commission, 2014. "The Bioeconomy Starts Here! Be Part Of It!", European Commission Horizon 2020 [online] Available at: https://ec.europa.eu/programmes/horizon2020/en/news/bioeconomy-starts-here-be-part-it (accessed: 6/1/16).

European Commission, 2014a. "Living Well, Within the Limits of Our Planet, 7th EAP, The New General Union Environment Action Programme to 2020", *European Commission* [Online] Available at: http://ec.europa.eu/environment/pubs/pdf/factsheets/7eap/en.pdf (accessed: 6/1/16).

European Commission, 2014b. "Where Next for the European Bioeconomy? The Latest Thinking from the European Bioeconomy Panel and the Standing Committee on Agricultural Research Strategic Working Group (SCAR)", *European Commission* [Online] Available at: http://ec.europa.eu/research/bioeconomy/pdf/where-next-for-european-bioeconomy-report-0809102014_en.pdf (accessed: 31/3/16).

Ellen MacArthur Foundation, 2015. "Circular Economy System Diagram" [Online] Available at: www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram (accessed: 31/3/16).

Eurostat, 2015. "Population on 1 January", *Eurostat* [Online] Available at: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=tps00001 (accessed: 6/1/16).

Fischer, G., H. T. Van Velthuizen and F. O. Nachtergaele, 2000. "Global Agro-Ecological Zones Assessment: Methodology and Results" in *IIASA Interim Report IR-00-064* FAO.

Forfás, 2009. "Sharing our Future: Ireland 2025: Strategic Policy Requirements for Enterprise Development", *Forfás* [Online] Available at: http://edepositireland.ie/bitstream/handle/2262/70627/forfas090713_sharing_our_future.pdf?sequence=1&isAllowed=y (accessed: 6/1/16).

Forfás, 2011. "Report of the Research Prioritisation Steering Group", *Forfás* [online] Available at: https://www.djei.ie/en/Publications/Publication-files/Research-Prioritisation.pdf (accessed: 7/2/15).

García-Vaquero, M. and M. Hayes, 2016. "Red and Green Macroalgae for Fish, Animal Feed And Human Functional Food Development", *Food Reviews International*, Vol. 32, No.1, pp. 15-45.

GBS, 2015. "Communiqué Global Bioeconomy Summit 2015: Making Bioeconomy Work for Sustainable Development", Berlin, 26th November 2015 [Online] Available at: http://gbs2015.com/fileadmin/gbs2015/Downloads/Communique_final_neu.pdf (accessed: 6/1/16).

German Bioeconomy Council, 2015. "Bioeconomy Policies around the World" [Online] Available at: http://gbs2015.com/fileadmin/gbs2015/Downloads/GBS2015_05_Bioeconomy_Around_World_Map.pdf (accessed: 6/1/16).

German Presidency, 2007. "En Route to the Knowledge-Based Bio-Economy", German Presidency of the Council of the European Union, Conference Report, 30 May 2007, Cologne. Available at: http://www.bio-economy.net/reports/files/koln_paper.pdf (accessed: 21/12/15).

Ghazinoory, S., Abdi, M. and Azadegan-Mehr, M. 2011. "Swot Methodology: A State-of-the-Art Review for the Past, A Framework for the Future", *Journal of Business Economics and Management*, Vol. 12, No. 1, pp. 24-48.

Government Of Ireland, 2012. "Delivering Our Green Potential", Government Policy Statement on Growth and Employment in the Green Economy [Online], Available at https://www.agriculture.gov.ie/media/migration/ruralenvironment/environment/bioenergyscheme/DeliveringOurGreenPotential171212.pdf (accessed on 7/1/16).

Grealis, E. and C. O'Donoghue, 2015. *The Economic Impact of the Irish Bio-Economy: Development and Uses* – Joint report issued by the Teagasc Rural Economy Development Programme and the Socio-Economic Marine Research Unit, NUI Galway, Ireland.

Hamed, I., F. Özogul, Y. Özogul and J. M. Regenstein, 2015. "Marine Bioactive Compounds and Their Health Benefits: A Review", *Comprehensive Reviews in Food Science and Food Safety,* Vol.14, No. 4, doi: 10.1111/1541-4337.12136.

Hayes, M. and J. Fagan, 2014. "Bioactive Peptides from Boarfish: Protein Extraction and Generation of Health Beneficial Peptide Hydrolysates Using Established Techniques", Conference Paper May 2014 [Online] Available at: https://www.researchgate.net/publication/264273999_Bioactive_peptides_from_Boarfish_Protein_extraction_and_generation_of_health_beneficial_peptide_hydrolysates_using_established_techniques (accessed: 31/3/16).

Hayes, M., B. Carney, J. Slater and W. Bruck, 2008. "Mining Marine Shellfish Waste for Bioactive Molecules: Chitin and Chitosan – Part B: Applications", *Biotechnology Journal*, Vol. 3, No. 7, pp. 878-889.

Hilgartner, S., 2007. "Making the Bioeconomy Measurable: Politics of an Emerging Anticipatory Machine", *Biosocieties*, Vol. 2, No. 3, pp. 382-386.

Hooghe, L. and G. Marks, 2003. "Unraveling the Central State, But How? Types of Multi-Level Governance!, *American Political Science Review*, Vol. 97, No. 2, pp. 233-243.

House of Lords, 2014. "Waste or Resource: Stimulating a Bioeconomy", 3rd Report of Session 2013-2014. Science and Technology Select Committee, United Kingdom.

Howley, P., C. O'Donoghue and K. Heanue, 2012. "Factors Affecting Farmers' Adoption of Agricultural Innovations: A Panel Data Analysis of the Use of Artificial Insemination among Dairy Farmers in Ireland", *Journal of Agricultural Science*, Vol. 4, No. 6, pp. 171-179.

Hynes, S. and T. Hennessy, 2012. "Agriculture, Fisheries and Food in the Irish Economy", *The World Economy,* Vol. 35, No. 10, pp. 1340-1358.

Jordan, N., G. Boody, W. Broussard, J. D. Glover, D. Keeney *et al*., 2007. "Sustainable Development of the Agricultural Bio-Economy", *Science*, Vol. 316, No. 5831, pp. 1570-1571.

Lewandoski, I., 2015. "Securing a Sustainable Biomass Supply in a Growing Bioeconomy", *Global Food Security,* Vol. 6, pp. 34-42.

Lin, G. T. R., Y. Shen and J. Chou, 2010. "National Innovation Policy and Performance: Comparing the Small Island Countries of Taiwan and Ireland", *Technology in Society*, Vol. 32, No. 2, pp.161-172.

Mahro, B. and M. Timm, 2007. "Potential of Biowaste from the Food Industry as a Biomass Resource", *Engineering in Life Sciences*, Vol. 7, No. 5, pp. 457-468.

Mandl, M. G., 2010. "Status of Green Biorefining in Europe", *Biofuels, Bioproducts & Biorefining*, Vol. 4, No. 3, pp. 268-274.

Marine Institute, 2015. "The Real Map of Ireland", *Marine Institute* [Online] Available at: http://www.marine.ie/Home/site-area/irelands-marine-resource/real-map-ireland (accessed: 6/1/16)

Matthews, A., 2000 *"Farm Incomes – Myth and Realities"*, Ireland: Cork University Press.

McCormick, K. and N. Kautto, 2013. "The Bioeconomy in Europe: An Overview", *Sustainability*, Vol. 5, No. 6, pp. 2589-2608.

McCormick, K., 2011. "The Emerging Bio-Economy in Europe: Exploring the Key Governance Challenges", World Renewable Energy Conference, Sweden, 8th-13th May 2011 [Online] Available at: http://www.ep.liu.se/ecp/057/vol10/005/ecp57vol10_005.pdf (accessed: 23/5/16).

McDonald, R., K. Heanue, K. Pierce and B. Horan, 2015. "Factors Influencing New Entrant Dairy Farmer's Decision-making Process Around Technology Adoption", *Journal of Agricultural Education and Extension*, Vol. 22, No. 2, pp. 163-177.

McGloughlin, J. S. and J. Sweeney, 2012. *Governance and Climate Change: Making the Transition to an Adapted Ireland. Climate Change Research Programme (CCRP) 2007-2013*. (20). Environmental Protection Agency, Johnstown Castle Estate, Wicklow, Ireland. ISBN 978 1 84095 462 3.

O'Donoghue, C. and T. Hennessy, 2015. "Policy and Economic Change in the Agri-Food Sector in Ireland", *The Economic and Social Review*, Vol. 46, No. 2, pp. 315-337.

O'Neill, F. H., J. R. Martin, F. M. Devaney and P. M. Perrin, 2013. "The Irish Semi-Natural Grasslands Survey 2007-2012", *Irish Wildlife Manual*s, No.78. National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht, Ireland.

Patari, S., A. Tuppura, A. Toppinen and J. Korhonen, 2015. "Global Sustainability Megaforces in Shaping the Future of the European Pulp and Paper Industry Towards a Bioeconomy", *Forest Policy and Economics*, doi:10.1016/j.forpol.2015.10.009.

Ragauskas, A. J., C. K. Williams, B. H. Davison, G. Britovse *et al.*, 2006. The Path Forward for Biofuels and Biomaterials, *Science*, Vol. 311, pp. 484-489.

Riordan, B., 2012. Estimation of the Contribution of the Biosector to Ireland's Net Foreign Earnings: Methodology and Results. MPRA Discussion Paper 45674. pp. 1-20.

Roberts, J., 2011. *"Environmental Policy",* 2nd edition, Oxon, Routledge.

Rosegrant, M. W., C. Ringler, T. Zhu, S. Tokgoz and P. Bhandary, 2013. "Water and Food in the Bioeconomy: Challenges and Opportunities for Development", *Agricultural Economics*, Vol. 44, p. 139-150.

Rustad, T., I. Storrø and R. Slizyte, 2011. "Possibilities for the Utilisation of Marine By-products", *International Journal of Food Science & Technology*, Vol. 46, No. 10, pp. 2001-2014.

SCAR, 2015. "Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy – A Challenge for Europe, 4th SCAR Foresight Exercise", Standing Committee on Agricultural Research [Online] Available at: https://ec.europa.eu/research/scar/pdf/ki-01-15-295-enn.pdf#view=fit&pagemode=none (accessed: 23/5/16).

Smyth, T., 2015. "The Challenges and Pitfalls of Marine Bioactive Characterisation" Presentation at NutraMara Conference 2015, Royal Dublin Society, Dublin, 29th June 2015 [Online], Available at http://www.nutramara.ie/nutramara-conference-2015/presentations/ (accessed: 6/1/16).

Socaciu, C., 2014. "Bioeconomy and Green Economy: European Strategies, Action Plans and Impact on Life Quality", *Bulletin of University of Agricultural Sciences and Veterinary Medicine*, Vol. 71, No. 1, pp. 1-10.

Stake, R. E., 1995. "*The Art of Case Study Research"*, Thousand Oaks, California: Sage.

Stoker, G., 1998. "Governance as Theory: Five Propositions", *International Social Sciences Journal*, Vol. 155, No. 42, pp. 17-28.

Sweeney T. and J. V. O'Doherty, 2016. "Marine Macroalgal Extracts to Maintain Gut Homeostasis in the Weaning Piglet", *Domestic Animal Endocrinology*, doi: 10.1016/j.domaniend.2016.02.002.

Teagasc (2016) "Teagasc Advisory Services" [online] Available at: www.teagasc.ie/areaunits/advisory services/ (accessed: 23/5/16).

UNEP, 2012. "Keeping Track of our Changing Environment" *United Nations Environment Programme* [online] Available at: http://www.unep.org/geo/pdfs/keeping_track.pdf (accessed: 6/1/16).

Vogt, A., 2014. "Turning Thistles to Plastics: Italy Opens Innovative Green Chemistry Complex", *The Freelance Desk* [Online] Available at: http://thefreelancedesk.com/turning-thistles-to-plastics-italy-opens-innovative-green-chemistry-complex/ (accessed: 7/1/16).

Yan, N. and X. Chen, 2015. "Don't Waste Seafood Waste", *Nature*, Vol. 524, pp. 155-157.

Yin, R. K., 2009. "*Case Study Research: Design and Methods",* 4th edition, Thousand Oaks, California: Sage.