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Review Article

BioGreen: Bioeconomy for the future

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The project has been named BioGreen because it develops a new method to assesses the potential of the bioeconomy in contribution to Ireland's sustainability goals. Bioeconomy refers to those parts of the economy that use renewable biological resources (biomass) from land and sea such as crops, forests, fish, animals, micro-organisms, and organic waste and residue to produce food, feed, materials, chemicals, fuels and energy (Potocnik, 2015; as cited in Devaney, 2017). The research is critical because we live in a world with increasingly limited resources. Ireland enjoys a marketing advantage for its domestic consumer food products due to its sustainable production practices. Development of a robust bioeconomy sector would further consolidate the country's position as a world leader in sustainability (Devaney and Henchion, forthcoming 2017).

Keywords: Ireland Bioeconomy, Bioeconomy, Ireland Sustainable Growth, bio value chains, Biomass, Life Cycle Assessment, economic/environment/social sustainability/feasibility indicators, Resource use and emission profile

Bioeconomy refers to all economic activity derived from scientific and research activity focused on biotechnology. In other words, understanding mechanisms and processes at the genetic and molecular levels and applying this understanding to creating or improving industrial processes. There are multiple reasons to support the development of bioeconomy value chains (McCormick and Kautto, 2013). First, the availability of fossil resources is becoming increasingly limited and its usage leads to global warming and associated drastic secondary effects. Although there are multiple technologies to produce renewable energy to substitute fossil fuels, such as wind or solar energy, the most economically feasible renewable replacement of hydrocarbon resources for material use is probably only possible through biomass production. Biomass is virtually omnipresent and therefore also available to economically disadvantaged and rural population across a country. Using biomass in novel value chains offers new job and income opportunities as well as the potential for development of more efficient innovative processes (McCormick and Kautto, 2013). However, public perception of competition between bioenergy and food resources (the "food versus fuel" debate) has emerged as a great obstacle in the acceptance of bioenergy (Pfau et al., 2014). Other concerns include potential regional land-use change implications and reduced water and nutrient supply due to divergence of resources to these newly developed bio-chains (Rosengrant et al., 2013). In a European Commission (EC, 2010) public consultation similar concerns were raised. The majority of respondents feared over-exploitation of natural resources and impacts on food security as the most relevant risks that needed assessment accompanying any potential bioeconomy development. Wicke et al., (2015) concluded that political promotion incentives and subsidies for liquid biofuels increased the global demand for biomass and consequently affected global food prices. Therefore, the EU changed its biofuel policies to only support second generation biofuels produced from lingo-cellulosic biomass, either from crop residues or from crops grown on waste land. Thus, the proactive role of EU has played a major role to create fertile ground for social acceptability and sustainability of the bioeconomy value chains.

Holistic overall assessment of the socio-economic and environmental performance of different bioeconomy value chains is important to aid evidence-based policy making. Currently, the most popularly accepted and extensively used method to assess environmental impacts is Life Cycle Assessment (LCA). LCA includes all processes from the extraction of resources to the end-of-life discarding i.e. "from cradle to grave". The end products of one value chain could be fed as an input to a new bioeconomy value chain (Carrez et al., 2015). In this study, we refer to "biomass supply" as "the process of biomass production, harvesting, pre-treatment, transport to the plant gate, use by consumer and discarding into a new value chain." The rationale behind choosing the wider chain is that sustainable production of biomass alone cannot ensure that this biomass is available to consumers and industry, if processing facilities, transport infrastructure or recycling units are missing (Lewandowski., 2015). In this study, LCA-based Product Environmental Footprint (PEF) recommended by the European Union is used to evaluate the economic and environmental performance of product-system supply chains. A comparison of the merits of the PEF against other popular methods and standards for environmental impact assessment can be found in Cristobal et al., (2016). The PEF is a multi-criterion measure of the environmental performance of goods and services from a life cycle perspective. PEF was produced for the overarching purpose of identifying and seeking to reduce the environmental impacts associated with goods and services, taking into account supply chain activities, as any other LCA methodology. But to make PEF more relevant than any other LCA, the EC developed Product Environmental Footprint Category Rules (PEFCRs) that provide category-specific guidance for calculating and reporting life cycle environmental impacts of products through the economic supply-chain in a consistent way. The PEF includes fourteen impact categories to ensure comprehensive evaluation of the environmental performance across the economic supply chain. However, it is common practice to add/limit the number of impact categories to the ones relevant to particular project. This also reduces data collection efforts. The objective of performing a LCA can be either (1) measure the consequences of altering a system, or (2) analyse the environmental impacts along the product life cycle. These two goals are frequently tackled by consequential LCA and attribution LCA, respectively (Cristobal et al., 2016). The LCA suggested in this study is

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largely based on the framework provided by the "methodology for environmental sustainability assessment" developed for the European Commission (EC, 2012), Bioeconomy Information System and Observatory (BISO) project. This methodology is largely based upon the LCA guidelines suggested by the EC PEF method and the International Reference Life Cycle Data System (ILCD) Handbook. To make the assessment more holistic, social sustainability would also be evaluated which is explained in the Section 3 of this document. All these measures would ensure consistent and robust life cycle results of bio-based products and their supply chains (Cristobal et al., 2016).

For example, biofuels are generally assumed to reduce carbon pollution compared to conventional fossil fuels, the conventional fossil fuel petrol was therefore included as a reference benchmark in this study. However, it is important to evaluate whether unintended trade-offs may occur, along with quantifying the extent of their impacts. The PEF-LCA provides mechanisms to evaluate such trade-offs. For instance: the LCA of bio-based ethanol report lower values for Ionising radiation (cancer effects), Ozone depletion and Climate change, but higher values for the remaining impact categories (such as Resource depletion and Eutrophication) compared to petrol. From the perspective of climate change, the actual use phase (combustion to generate energy) CO2 equivalent emissions per km from petrol at 210 g km−1 are around six times higher than the ones from bio-based ethanol E85 at 37 g km−1. But, when considering the CO2 eq. emissions along the whole LCA chain, the difference between bio-based ethanol and petrol is markedly reduced (Cristobal et al., 2016). It is because while ethanol combustion is relatively environment friendly but ethanol production (including sugar production, fermentation and ethanol separation) causes a lot of emission in the category of Fecotox (Ecotoxicity for aquatic fresh water) and HH,nce (Human toxicity – non-cancer effects) (Cristobal et al., 2016). Thus, unintended trade-offs could vastly reduce the sustainability of a bio-value chain.

Finally, the end-of-life of any product depends on the biodegradability potential of the material. For example, Pietrini et al., (2007) concluded that the use of PHAs (biodegradable Polyhydroxyalkanoates polymers) biocomposite materials presented environmental benefits compared to the fossil materials when recycling the product because PHA materials could be shaped into products for different applications (packaging, medical devices etc).

Research Questions and Specific Research Methods

The preliminary questions were based on the final outcome desirable rather than them being so preliminary that defining boundaries for the research would have become difficult. It is important to have determined research aims/objective and questions at the start rather than researching without boundaries. It helps to keep in mind the relevant population, the intervention, the outcome and study design when framing these questions (Yin, 2009). For the same reason filtering the content becomes critical to best suit the current macroeconomic, geographic, technological expertise of Ireland. This also helps avoid biases which may distort the results in the Irish context. Although the bioeconomy has received much attention in Ireland, a country which prides itself on its sustainability ideals, not a very significant amount of peer-reviewed bioeconomy literature exists in the Irish context, except Devaney (2017) and Devaney and Henchion (forthcoming 2017). Therefore, the scientific papers selected for review related to countries similar to Ireland in economic, environmental and social context. In case the studies are from a country with different priorities and contexts, only the parameters that were suitable for Ireland were adopted.

The project goes forward and suggests a methodology to evaluates the economic, environmental and social sustainability of different bioeconomy value chains. The value chains are themselves developed by Teagasc in collaboration with respective experts in their fields to avoid bias (Devaney and Henchion, 2016). The primary source of information were database search engines including Google Scholar, Teagasc Online Library, UCD One Search and Elisilver's database. The database search was the primary source of information because a written proof can be accessed anytime in the future and the reference can be cited correctly. The Bioeconomy project was intended to be a four-month undergraduate module research project, therefore to fulfil the research objectives in the given time frame, it was considered appropriate to make it a desk based literature review project. The evaluation questions specifically to be searched on database libraries would be:

1) What are the economic sustainability/feasibility indicators?
2) What are the environment sustainability/feasibility indicators?
3) What are the socio-cultural sustainability/feasibility indicators?
4) What are the different quantitative/qualitative sustainability/feasibility criteria?

The criteria will be chosen based on their relevance to Ireland by qualifying the search to include Ireland after the initial overarching database search has been conducted.

Section 1: Economic Sustainability

Rosegrant et al., (2013) defines economic sustainability as "Economic growth driven by the development of renewable biological resources and biotechnologies to produce sustainable products, employment and income."

Economic Sustainability Criteria development rationale

The following is the list of processes from acquisition to end of life that a product undergoes in the cradle to grave PEF-LCA. All these steps need to be accounted for in a holistic economic LCA assessment to estimate the approximate cost of any value chain. Considering, it is a factual list of steps that any product undergoes from the stage of acquisition to end of life discarding, not a significant critical analysis is required. However, it is a common practice to limit the steps in the table to conduct a shorter economic analysis and save unnecessary effort (European Commission, 2010):

- Gate-to-gate(production-to-consumer) activities/processes;
- Upstream or downstream phases;
- Key supply-chain activities for the product category;

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Key environment factor impact categories for the product category.

Table 1: Economic Sustainability Criteria (Source: European Commission, 2010)

Aspect	**Definition / Specifications / Examples**
Biomass acquisition and pre- processing	The biomass acquisition and pre-processing stage starts when resources are extracted from nature and ends when the product components enter (through the gate of) the product's production facility. Processes that may occur in this stage include e.g.: • Mining and extraction of resources; • Pre-processing of all material inputs to the studied product system; • Conversion of recycled material; • Photosynthesis for the biogenic fraction of the bio-based product; • Cultivation and harvesting of trees or crops; • Transportation within and between extraction and pre-processing facilities, and to the production facility.
Capital goods	Examples of capital goods that should be included (if applicable) are: • Machinery used in extraction/production processes; • Buildings; • Office equipment; • Transport vehicles; • Transportation infrastructure. *Linear depreciation should be used for capital goods. The expected service life of the capital goods should be taken into account (and not the time to evolve to an economic book value of "0").*
Production, distribution and storage	Products are distributed to users and may be stored at various points along the supply chain. Examples of processes related to distribution and storage that should be included (if applicable) are: • Energy inputs for warehouse lighting and heating; • Use of refrigerants in warehouses and transport vehicles; • Fuel use by vehicles.
Use stage	The use stage begins when the consumer or end user takes possession of the product and ends when the used product is discarded for transport to a recycling or waste treatment facility. Examples of use-stage processes that should be included (if applicable) are: • Use/consumption patterns, location, time (day/night, summer/winter, week/weekend), and assumed use stage lifespan of products; • Transportation to the location of use; • Refrigeration at the location of use; • Preparation for use (e.g. microwaving); • Resource consumption during use (e.g. energy consumption for microwaving, water use, etc.); • Repair and maintenance of the product during the use stage.
Logistics	Transport parameters that should be taken into account are: • **Transport type**: The type of transport, e.g. by land (truck, rail, pipe), by water (boat, ferry, barge), or air (airplane), should be taken into account; • **Vehicle type and fuel consumption**: The type of vehicle should be taken into account by transport type, as well as the fuel consumption when fully loaded and empty. An adjustment should be applied to the consumption of a fully-loaded vehicle according • Transport distance; • Fuel production. Additional transport parameters that should be taken into account (if relevant) are: transport infrastructure, additional resources and tools such as cranes and transporters, allocation for personal transport based on time or distance, allocation for staff business travel based on time, distance or economic value.
End of Life (EoL)	The EoL stage begins when the used product is discarded by the user and ends when the product is returned to nature as a waste product or enters another product's life cycle (i.e. as a recycled input). Examples of EoL processes that (if applicable) should be included in the assessment are: • Collection and transport of end-of-life products and packages; • Dismantling of components; • Shredding and sorting; • Conversion into recycled material; • Biological treatment, e.g. composting and anaerobic digestion; • Littering; • Incineration and disposal of bottom ash; • Landfilling and landfill operation and maintenance; • Transport required to all EoL treatment facilities. A comprehensive source of technical information about management of biodegradable waste and methodological specification on life-cycle modelling is provided by the JRC technical report "Supporting environmentally sound decisions for bio-waste management – A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA)" (EC, 2010). Life cycle inventories for these EoL processes have to be typical of the bio-product groups and of the materials contained in them.
Accounting for electricity use	For electricity from the grid consumed upstream or within the defined assessment boundary, supplier-specific data should be used if available. If these are not available, country-specific consumption-mix data should be used of the country in which the life cycle stages occur. For electricity consumed during the use stage of products, the energy mix should reflect ratios of sales between countries or regions. Where such data are not available, the average EU consumption mix, or otherwise the most representative mix, should be used.

Economic Sustainability Discussion

Broody et al., (2005) believe that expenditure on capital goods (Capital goods step) in farm set-up and equipment to switch to bioeconomy agriculture should be minimal and ideally zero. For example, there is generally no extra cost to switch from conventional tillage (uses cultivation, ploughing and harrowing for seedbed preparation and weed control) to conservational tillage (soil cultivation that leaves the previous year's crop residue on the field before and after planting the next crop to reduce soil erosion and runoff) in terms of equipment requirements.

Zhuang et al., (2015) also believe that the overall LCA assessment cash flow of the individual (farmer) does not change significantly when switching priority from the cash flow maximization objective to the minimization of global warming potential or eutrophication potential. Their research concludes that in environmentally friendly agriculture, significant environmental benefits can be reaped by avoiding the worst-case environment scenario while possibly only incurring a small sacrifice in economic profits. But research also proves that consumers are generally willing to buy environmentally sustainable products. Therefore, even that small sacrifice in profits can be overcome.

Methodology of Assessment

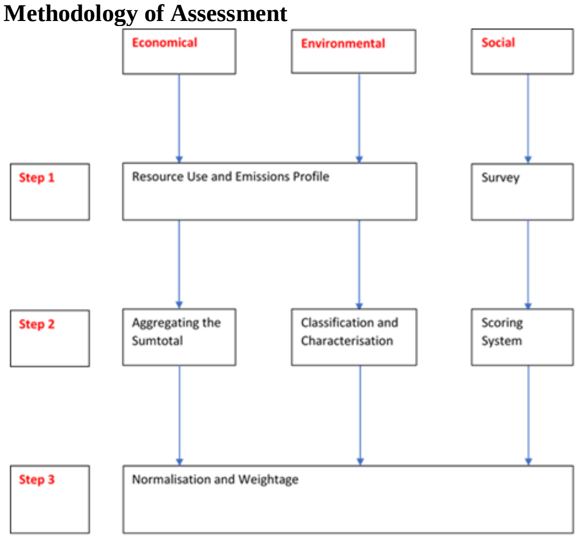

Figure 2. The steps of assessment for economic, environment and social criteria

Economic Sustainability Evaluation steps:

1) Resource Use and Emission Profile of the value chain
2) Aggregating the sum-total of various resources used
3) Normalization and weightage depending on relative importance of various categories

Economic Sustainability Evaluation

Step 1: Resource Use and Emissions Profile (European Commission, 2010)

As data collection is completed, a resource use and emissions profile is built i.e. an inventory of all inputs and output flows relative to the environmental footprint boundaries (Table 2). An inventory (profile) of all material/energy resource inputs/outputs and emissions into air, water and soil for the product supply chain needs to be compiled to conduct the PEF assessment.

Ideally, the supply chain to be considered would depend on product-specific data (exact life cycle depicting the supply chain, use, and end-of-life stages as relevant). Therefore, directly collected, product-specific inventory data should be used wherever possible. However, generic data can be used if that is more representative or to save data collection efforts.

All complex/non-elementary flows in the Resource Use and Emissions Profile shall be transformed into elementary flows ("material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation") to ensure comparability of PEF studies. For example, waste flows should not be reported as kg of household waste or hazardous waste, but separately into water, air and soil due to different environmental impacts of wastes discharged in different media (European Commission, 2010).

Table 2: Example of a Resource Use and Emission Profile

Parameter	Unit/kg	Amount
Energy consumption (non-elementary)	MJ	115.5
Electricity (elementary)	MJ	34.6
Fossil Fuel (elementary)	MJ	76
Others (non-elementary)	MJ	4.9
Non-renewable resources (non-elementary)	kg	2.7
Natural gas (elementary)	kg	0.59
Natural gas, feedstock (elementary)	kg	0.16
Crude oil (elementary)	kg	0.57
Crude oil, feedstock (elementary)	kg	0.48
Coal (elementary)	kg	0.66
Coal, feedstock (elementary)	kg	0.21
LPG (elementary)	kg	0.02
Hydro power (MJel) (elementary)	MJ	5.2
Water (elementary)	kg	12400
Emissions to air (elementary flows)		
CO_2	g	5,132
CH_4	g	8.2
SO_2	g	3.9
No_x	g	26.8
CH	g	25.8
CO	g	28
Emission to water (elementary flows)		
COD Mn	g	13.3
BOD	g	5.7
Tot-P	g	0.052
Tot-N	g	0.002

(Source: European Commission, 2010)

Table 3. Environment Sustainability Criteria

Impact Category	Impact Assessment Model	Impact Category indicators	Source
Climate Change	Bern model - Global Warming Potentials (GWP) over a 100 year time horizon.	kg CO2 equivalent	Intergovernmental Panel on Climate Change, 2007
Ozone Depletion	EDIP model based on the ODPs of the World Meteorological Organization (WMO) over an infinite time horizon.	kg CFC-11 equivalent	WMO, 1999
Ecotoxicity for aquatic fresh water	USEtox model	CTUe (Comparative Toxic Unit for ecosystems)	Rosenbaum et al., 2008
Human Toxicity - cancer effects	USEtox model	CTUh (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008
Human Toxicity – non-cancer effects	USEtox model	CTUh (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008
Particulate Matter/Respiratory Inorganics	RiskPoll model	kg PM2.5 equivalent	Humbert, 2007
Ionising Radiation – human health effects	Human Health effect model	kg U^{235} equivalent (to air)	Dreicer et al., 1995
Photochemical Ozone Formation	LOTOS-EUROS model	kg NMVOC equivalent	Van Zelm et al., 2008 as applied in ReCiPe
Acidification	Accumulated Exceedance model	mol H+ eq	Seppälä et al.,2006;
Eutrophication – terrestrial	Accumulated Exceedance model	mol N eq	Seppälä et al.,2006;
Eutrophication – aquatic	EUTREND model	freshwater: kg P equivalent marine: kg N equivalent	Struijs et al., 2009 as implemented in ReCiPe
Water Footprint (Qualitatative)	ISO14046	water scarcity, eutrophication, toxicity etc	Ridoutt, 2016
Resource Depletion – mineral, fossil	CML2002 model	kg antimony (Sb) equivalent	van Oers et al., 2002
Land Transformation	Soil Organic Matter (SOM) model	kg (deficit)	Milài Canals et al., 2007
Land Projection	ratio of crop-to-residual biomass	available quantities of lignocelluloses	Khoo et al, 2010
Reduced Externality Cost (Qualitataive)	reduced sedimentation or reduced flooding	varies	Daniels and Gilliman, 1996
Deforestation	Forested area as compared to total land area	hectare/acre/square km	Millennium Declaration, UN 2010
Fish stocks	Proportion of fish stocks within safe biological distance	percentage	Millennium Declaration, UN 2010
Nitrogen Cycle (part of boundary with the phosphorous cycle)	Amount of di-nitrogen removed from the atmosphere from human use	tonnes	Rockström et al., 2009
Soil erosion	per acre of cropland	tonnes	Current author
Groundwater quality index	solid debris in water	ppm	Current author
Coastal Water Quality	chlorophyll-a concentrations	NASA SeaWiFS	NASA, 2012
Ecological footprint	area of ecologically productive land needed to maintain population	hectare/acrea/square km	Wackernagel and Rees, 1996
Usage of waste in value chain	proportion of total input	kg/tonnes	Current author

(Adapted from European Commission, 2010)

Environment Sustainability Discussion

Most quantitative criteria can be considered qualitative if we set a certain threshold for the parameter beyond which any result is positive and below which any result is negative. Some hazardous products might be produced in factories which are located close to the sea. The waste may therefore effect marine water instead of fresh water. The impact would likely be different and therefore needs to be accurately quantified.

It is important to realise that the above-mentioned environment impact categories are limited and other environmental impact categories may need to be considered when relevant. For example, biodiversity impacts due to land use changes may occur in association with a specific site or activity. This may not only require defining a new impact category but also an additional qualitative description where impacts cannot be linked to the product supply chain in a quantitative manner. Such additional methods should not be considered distortion but instead be viewed as complementary to the default list of environment sustainability (European Commission, 2010).

Reduced externality costs like reduced sedimentation should be considered because for example riparian buffers reduce overland runoff to streams (Daniels and Gilliman 1996), wetland restoration can reduce flood flow volumes (Shultz and Leitch 2003) and other negative externalities. Modelling has shown that reducing runoff by 10% within a watershed may reduce the flood peaks with a 2 to 5 year return period by 25% to 50% and might reduce a 100-year flood by about 10% (USACE 1995). These positive externalities need to be quantified and expressed (where relevant) in the environmental sustainability assessment for a holistic overview of a value chain.

Only fourteen impact categories were suggested in the EC PEF and other ten impact categories were added to customize the environment criteria for bioeconomy projects in Ireland. For example, water footprint was added because, while Ireland does not suffer from water deficiency due to water usage but in globally linked value chains water could impact the sustainability score of any value chain significantly. Other indicators such as fish stock were added because Ireland is a small island country and healthy fish population keeps the coast sustainable and economy viable. Therefore, it was considered a relatively high weighted environment criteria in the Irish context (Current author).

Environment Sustainability Evaluation steps:

1) Resource Use and Emission Profile of the value chain
2) Classification and Characterization of different environment factors into a single category
3) Normalization and weightage depending on relative importance of various categories

Environmental Sustainability evaluation

Step 1: Resource Use and Emissions Profile: Same as Economic Sustainability Evaluation

Step 2: Classification and Characterization

Classification requires assigning the material/energy inputs and outputs included in the research criteria developed to the relevant impact categories. For example, during the classification phase, all inputs/outputs that result in greenhouse gas emissions are assigned to the climate change category. Similarly, those that result in emissions of ozone-depleting substances are classified to the Ozone Depletion category. In some cases, an input/output may contribute to more than one impact category. For instance, chlorofluorocarbons (CFCs) contribute to both Climate Change and Ozone Depletion (European Commission, 2010).

Example: Classification of data for a random T-Shirt study

In the following Table A and Table B illustrations for a random t-shirt study, the different air pollution emissions (for example: Carbon dioxide, Methane) are classified into stand-alone environment factors (for example: climate change, acidification etc).

Table A: Classification of data in the climate change impact category:

Carbon Dioxide	CO2	Yes
Methane	CH4	Yes
Sulphur Dioxide	SO2	No
Oxides of Nitrogen	NOx	No

Table B: Classification of data in the acidification impact category:

Carbon Dioxide	CO2	No
Methane	CH4	No
Sulphur Dioxide	SO2	Yes
Oxides of Nitrogen	NOx	Yes

(Source: European Commission, 2010)

Characterization factor (CF) refers to the calculation of the magnitude of the contribution of each classified input/output to their respective impact categories, and aggregating the contributions within each category. This is carried out by multiplying the values in the assessment inventory by the relevant substance/resource specific characterization factor for each impact category. They represent the impact intensity of a substance relative to a common reference substance for a given impact category. For example, all greenhouse gas emissions inventoried are weighted in terms of their impact relative to carbon dioxide equivalent, which is the reference standard of this category. This allows for the aggregation of predicted impact potentials and expression in terms of a single equivalent substance for each impact category. For instance, global warming potential for methane equals 25 CO2 – equivalents and its impact on global warming is thus 25 times higher than that of CO2 (European Commission, 2010).

Example: Calculation of EF impact assessment

In the following Table C and Table D illustrations, taking methane as an example, emission value (8.2) in the assessment inventory is multiplied by the relevant substance/resource specific characterization factor (25) to get a common unit measure (0.205 carbon equivalent) that is subsequently easy to aggregate.

Table C: Global warming CF

Carbon Dioxide	CO2 g	5,132 x 1 = 5.132 kg CO2eq
Methane	CH4 g	8.2 x 25 = 0.205 kg CO2eq
Sulphur Dioxide	SO2 g	3.9 x 0 = 0 kg CO2eq
Oxides of Nitrogen	NOx g	26.8 x 0 = 0 kg CO2eq
Total =		5.337 kg CO2eq

Table D: Acidification CF

Carbon Dioxide	CO2 g	5,132 x 0 = 0 Mol H+ eq
Methane	CH4 g	8.2 x 0 = 0 Mol H+ eq
Sulphur Dioxide	SO2 g	3.9 x 1.31 = 0.005 Mol H+ eq
Oxides of Nitrogen	NOx g	26.8 x 0.74 = 0.019 Mol H+ eq
Total =		0.024kg Mol H+ eq

(Source: European Commission, 2010)

Results and conclusions of certain selected Environment Sustainability studies

To curb significant climate change, and to adapt to a world of increasingly limited resources, it is critical to decouple economic growth from environment degradation. Ireland is in a strong position to use data, knowledge and innovation as the feedstock instead of oil, and produce more from less and harness opportunities in waste streams. For example through marine waste for biochemical conversion or forestry pulp for bioenergy creation (Devaney and Henchion, 2016).

However, many research findings reveal that regions with major production potential might be distant from the biomass/bioenergy markets in developed countries such as Ireland (Lauri et al., 2014). This has given birth to a controversy on the practicality of the bioeconomy to import biomass from areas of low food security into economically prosperous regions of world. Therefore, experts suggest developing a model that enables the impacts of the various factors (policy measures, land-use efficiency, crop productivity etc.) on the bioeconomic sector to be assessed. Therefore, sustainability assessment models should provide information ex-ante on potential impacts of these contributors on biomass sustainability, land-use patterns, resource use (e.g. water and phosphorus) and other indicators for sustainable development, such as job creation and GHG emissions (Lewandowski, 2015).

Section 3: Social Sustainability

Social sustainability is the ability of a community to develop processes and structures which not only meet the needs of its

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current members but also support the future generations to maintain a viable community (Business Dictionary, 2017).

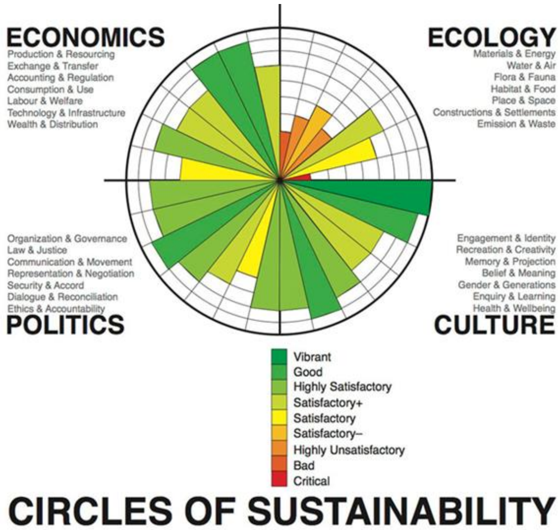

Figure 2: Circles of Sustainability (Source: Magee et al., 2013)

A recent approach believes that all of the domains of sustainability are social: including ecological, economic, political and cultural sustainability (Magee et al., 2013). The social sustainability is defined as human embeddedness in the environment. Therefore, social sustainability encompasses all human activities, it is more than just focused intersection of economics, the environment and the social.

Social Sustainability Criteria development rationale

The following dimensions need to be accounted for in a holistic environment LCA assessment to estimate the approximate social benefits and costs for any value chain.

The primary basis for assessing public policies and the regulatory framework is the improved and sustainable delivery of those functions of economy (agriculture) for which there is a particular societal demand. However, several studies have argued against the classical evaluation tools like cost-benefit analysis for multifunctional/bioeconomy agriculture policies citing them to be limited in scope, and suggest the combinations of quantitative, qualitative, and consultative methods like local income and regional economy; regional agricultural sector, social equity and cohesion, local quality of life, rural population stability and local environment to be more comprehensive (Knickel and Kroger, 2008). Therefore, this study includes socio-individual, socio-institutional, socio-economic and socio-environmental aspects to assess the social sustainability of a particular value chain.

The sustainability framework developed by USEPA (USEPA, 2012), which includes an integrated and comprehensive approach for social sustainability evaluation, formed the basis of Social Sustainability Evaluation Matrix (SSEM) development (Reddy et al., 2014). The socio-individual and socio-institutional dimensions encompass indicators that pertain to overall impacts on standard of living, education, population growth, justice and equality, community involvement, and fostering local heritage. The socioeconomic dimension comprises indicators relating to business ethics, fair trade and worker's rights. The socio-environmental dimension accounts for the consumption of natural resources, environmental management, and pollution prevention in all environmental media such as air, water, land and waste. The incorporation of all four social dimensions and their corresponding indicators into the SSEM tool is perceived by ICSI 2014: Creating Infrastructure for a Sustainable World, to be best representative of the overall resulting social impacts through the entire life cycle of a project (Reddy et al., 2014). The SSEM is excel based and therefore flexible and accommodates the use of additional key areas to facilitate project specific criteria application and quantification of the social impacts. While, SSEM might be a simplistic method to generate information but it overcomes the ethical issues of scientists making decisions for the masses, through a time and cost effective method (Current author). SSEM has found a number of applications to compare, assess and allow for informed decisions on environmental remedial projects, including an Indian ridge marsh project (Harclerode et al., 2015).

Table 4: Social Sustainability Criteria

Dimension	Key Theme Area
Socio-individual	Effect of proposed remediation on quality-of-life issues during and post-construction/remediation
	Crime
	Cultural identity and promotion
	Overall public health and happiness
	Population demographics (age, income)
	Gender equity
	Justice and equality
	Care for the elderly
	Care for those with special needs
	Degree to which post-remediation project will result in skills development
	Degree to which post remediation project will result in leadership development opportunities
	Enhancement of community/civic pride resulting remediation and post-remediation project
	Degree to which tangible community needs are incorporated remediation design
	Transformation of perceptions of project and environs within greater community
	Potential of post-remediation project to enhance cultural diversity in community
	Potential of incorporating newcomers to community
	Potential of remediation to foster better health through enhanced recreational opportunities
	Enabling knowledge management (including access to E-knowledge)
Socio-Institutional	Appropriateness of future land use with respect to the community environment
	Degree of land use planning fostered by proposed construction/remediation
	Involvement of community in land use planning decisions
	Enhancement of commercial/income-generating land uses
	Improvement and enhancement of market-rate housing stock
	Improvement and enhancement of affordable housing stock

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	Enhancement of recreational facilities
	Enhancement to the architecture/aesthetics of built environment
	Enhancement and participation of school system (i.e., new buildings) in community
	Enhancement and participation of new congregations and facilities in community
	Enhancement and participation of government institutions (i.e., new facilities) in community
	Degree of "grass-roots" community outreach and involvement
	Involvement of community organizations pre- and post-construction/remediation
	Enhancement of cultural heritage institutions within community
	Involvement and enhancement of community-based charitable organizations
	Incorporation of green and sustainable infrastructure into construction/remediation
	Enhancement of transportation system improvements
	Trust, voluntary organizations and local networks (also known as social capital)
Socio-Economic	Disruption of businesses and local economy during construction/remediation
	Employment opportunities during construction/remediation
	Employment opportunities post-construction/remediation
	Degree of project investment toward Local Business Entities (LBEs)
	Degree of project investment toward Disadvantaged Business Entities (DBEs)
	Post-construction/remediation 3rd party business generation
	Relative degree of increased tax revenue from Site Reuse
	Relative degree of increased tax revenue from nearby properties
	Degree to which green/sustainable or other "new economy" businesses may be created
	Degree of stimulated informal activities/economy
	Degree of anticipated partnership and collaboration with outside investors/institutions
Socio-Environmental	Remediation of naturally-occurring contaminants (i.e., naturally-occurring asbestos, radon)
	Remediation of anthropogenic contaminants at "chronic" concentrations
	Remediation of anthropogenic contaminants at "acute" concentrations
	Remediation of pervasive "economic poisons" or other pervasive conditions endemic in community
	Degree of protection afforded to remediation workers by proposed remediation
	Degree of disruption (noise, truck traffic) from proposed remedial method to the surrounding neighborhoods
	Degree of contaminant removal/destruction vs. in-place capping or immobilization
	Degree of future characterization/remediation required by re-zoning or altered land use
	"Greenness"/sustainability of proposed remedial action
	Incorporation of green energy sources into remediation activity
	Restoration or impact to productive surface water or groundwater use
	Degree proposed remediation will affect other media (i.e., emissions/air pollution)
	Potential of future environmental impact (i.e., diesel exhaust from trucks)

(Source: Reddy et al., 2014)

Social Sustainability Discussion

The first stakeholders in the biomass supply chain are primary producers i.e. farmers. Farmer participation is critical for the success of any bioeconomy initiative. Whereas the adoption of biogas has for example allowed German farmers to keep the extra income generated by electricity and heat on their own farms, other bioenergy models have provided fewer economic incentives to farmers. The lack of involvement of smallholder farmers in the development of biofuels and bioenergy has been criticized to be a major reason for their poor acceptance in the wider community. However, there is a socio-individual learning process where farmers may slowly and reluctantly adopt multifunctional agriculture in response to incentives or regulations (carrots or sticks), and then gradually internalize the new behaviors (Stobbelaar et al. 2009). De Schutter (2011) criticises “land grabbing” – the purchasing of land, mainly in Africa and Asia, by big companies – because it limits the access of local rural communities to land and water resources, and hinders the socio-economic development. The longer the market chain, the more difficult it is for primary producer to access the market. The development of biomass certification schemes has on the ground actually disadvantaged small producers on a socio-institutional level due to the additional costs for controls and organizational requirements (Markelova et al., 2009).

Social Sustainability Evaluation steps:

1) Survey to find out population perception about the project
2) Convert the perceptions into the SSEM scoring system
3) Normalization and weightage depending on relative importance of various categories

Social Sustainability Evaluation:

Step 1: Social sustainability evaluation: It might be difficult to quantify the value of parameters such as cultural identity and promotion, overall public health and happiness etc. It is recommended to conduct a survey about the affected population and take the mean of the results as the value of that parameter (Current author).

Step 2: A scoring system has been shown in Table 5, with zero value for no impacts, +1 or +2 for positive impacts, and -1 or -2 for negative impacts (Reddy et al., 2014). The total sum of all categories is considered along with “no action” option. The scores can be given based on pre-determined threshold for country specific economic, environment and environmental thresholds. For example, if more than 80% of population believes a particular aspect of social sustainability will be improved by implementing a new biochain, then the factor can be ranked 2, whereas if only 50% population thinks that a social sustainability factor would be improved, the factor can accordingly be ranked 0. This system provides an easy but efficient way to rank the criteria.

Table 5: Scoring system

Positive Impact		No Impact or N/A	Negative Impact	
Ideal	Improved		Diminished	Unacceptable
2	1	0	-1	-2

Results and conclusions of certain selected Economic Sustainability studies

A major push for multifunctional agriculture in Europe is the support for diversified rural employment opportunities. Irish farmers can find many opportunities to diversify within the realm of bioeconomy. 30% farmers in the U.K. and about 59% farmers in Germany are involved in some kind of diversification (Renting et al., 2009). Irish farmers can (Devaney and Henchion, 2016):

- use existing or novel transformation technologies to convert agricultural waste and by products to produce biogas.
- use existing or novel transformation technologies to convert horticulture waste into bio-compostable packaging
- transform marine waste to high value functional foods.
- Transform seaweed for food or cosmetic applications.

These activities increase the income level of the rural population, enhances employment opportunities, and positively influences rural infrastructure. (Sikorska-Wolak, 2006). Ireland needs to develop the areas of strength in bioenergy with further innovation by engaging stakeholders across the board. Ireland can propel public acceptance and consumer demand by not only technology development, but the state would also need to invest in a holistic programme for market development of bio economy products. The government would need to play its role in social sustainability of the novel bio-chains.

Final step for economic, environmental and social criteria

Normalization and Weighting (European Commission, 2010)

Normalisation is a recommended step, where the impact assessment results are multiplied by normalisation factors (NFs). This is done in order to calculate and compare the magnitude of their contributions to the impact categories relative to a reference unit. As a result, dimensionless normalised results are obtained. They reflect the burdens attributable to a product relative to the reference unit, such as per capita for a given year and region. This allows the relevance of the contributions, made by individual processes, to be compared to the reference unit of the considered impact categories. For example, impact assessment results may be compared to the same impact assessment results for a given region such as the EU-28 and on a per person basis. In that case they would reflect person-equivalents relative to the emissions associated with the EU-28. Normalised impact assessment results do not, however, indicate the severity or relevance of the respective impacts (European Commission, 2010).

Weighting is a mandatory step for projects with many criteria whose importance/impact potential varies significantly. Weighing supports the interpretation and communication of the results of the analysis. At this step, impact assessment results (normalised results, for example) are multiplied by a set of weighting factors that reflect the perceived relative importance of the considered impact categories. Weighted impact assessment results can then be compared to judge their relative importance. They can also be aggregated across impact categories to obtain several cumulative values or a single overall impact indicator. Weighting requires making value judgements as to the respective importance of the considered impact categories depending on the cultural/ political viewpoints or economic considerations (European Commission, 2010).

Not only does the weighing of the economic, environment and social categories vary across geographies and time scale but the relative importance of each parameter also varies significantly. The weighting assigned to a particular parameter depends on the economic, environment and social context of the region in the particular time.

Table 6: Sample weighing

Criteria	Weight	Score
Economic	40	TBD
Environment	40	TBD
Social	20	TBD
Sustainability Score	100	

Like table 6, each of the economic, environment and social criteria factors can have different weight assigned to them that aggregate together to form respective scores of individual sections which are finally added together in Table 6 to judge the sustainability of the value chain under consideration.

A sensitivity analysis could be undertaken to identify the variables which affect the sustainability score significantly. The test could be run with different weights attached to variable to expose inappropriate forecasts and thus guide the decision maker to concentrate on relevant variables (Current author).

Conclusion

Scientific review to develop the economic, environmental and social research criteria and methodology to subsequently evaluate the sustainability of different biochains in the Irish bioceconomy

This study has developed novel criteria and methodology to judge the economic, environment and social sustainability of bioeconomy value chains. However, the study realises that to develop any model, the first step is defining what is considered "sustainable" in the context of a specific project in its geographical and societal setting. Hence, to provide a universal application, this methodology allows to introduce new criteria easily and change relative weights of different criteria according to the geographic and timely needs of different projects. The study falls short of itself translating the methodology into a computer application where the users just need to input relative weights and numbers values and they are immediately presented with a sustainability and sensitivity analysis scores.

There are manifold trade-offs between sustainability goals and conflicting stakeholder perceptions of sustainability. Consequently, the simultaneous fulfilment of all sustainability criteria becomes next to impossible (Lewandowskie, 2015). Therefore, highest weighed average value chain should be prioritized for implementation.

Provide a new template of a detailed methodology to subsequently conduct sustainability assessment and determine the most optimal biochain for other countries as well

Techniques that support value-chain optimization include life-cycle assessment (LCA), such as the PEF-LCA suggested in this study. The strength of this approach is that it accommodates for various biochains across different geographies of the world. New economic, environmental or social factors can be introduced when required and the PEF-LCA approach provides an easy way to calculate sustainability. However, any LCA methodology would only depict material and energy flows along the value chain. The Biomass Value Chain Model (BVCM) a spatial – temporal model was recently developed for the UK to provide a more holistic assessment of economic and environmental performance of complete bioenergy value chains by taking resource availability and demand into account, thus helping to decide where and when to invest in conversion technologies (Samsatli et al., 2015). This model could represent a first step towards the higher level of integration which aims at assessing the combined effects of introducing bio-based value chains on the bioeconomic system as a whole (Lewandowskie., 2015). Considering the limited time run of this study, it was not possible to incorporate the features of BVCM in this study. However, there is no globally accepted model of bioeconomy value chain evaluation. Further, the bioeconomy sector is so dynamic that most assessment models keep on evolving with time. The best approach to develop a sustainability model is to utilize a regionally accepted assessment model and cater it to the needs of the geography and society where the project is to be conducted.

Suggestion for future studies:

1) Jordan et al., (2007) recommends the use of demonstration projects that do not require large scale to extract the most optimal value from a value chain. The new bioeconomy research projects across the globe almost always develop demonstration pilot projects first to implement the same technology on a larger scale subsequently. Therefore, it is recommended to pilot the methodology developed in this study on a couple of biochains developed in Ireland (For example by Devaney and Henchion, 2016) and adjust the criteria accordingly.
2) How do the weights of criteria change with a particular emphasis on social sustainability, when the same methodology developed in this study is run for relatively poor African and Asian countries?
3) What is public perception/"willingness to pay" for bioeconomy products? What products would domestic and global consumers most likely buy out the value chains developed by Devaney and Henchion (2016) considering the value chains developed there are most relevant to Ireland.

What public investments need to be made in the coming decades to prepare the bio-economy of tomorrow? What legal regulatory issues need to be addressed to commercialise the new innovative products in Ireland?

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