Environmental and Ethical Decision Making in Irish Food Business

Full Report

Contents

1 Introduction

1.1 Background

The world is currently facing into a series of transformations which will, and have already begun to, alter the shape of life on earth for both humans and non-humans alike. These overlapping and interconnected changes include anthropogenic climate change, an already near catastrophic collapse in plant and animal biodiversity globally and rapidly expanded levels of global wealth inequality. Each of these effects, all of which have accelerated significantly in the last fifty years, are intrinsically linked to global systems of production, trade and disposal. In human terms, the effects of these changes will be varied and unequally distributed in space, time and dependent on economic factors. Nevertheless, each of these transformations present significant threats to human life and ways of life in all parts of the globe. Beyond the human-centred impacts these changes will have significant effects on the variety and existence of many ecosystems.

1.2 Climate Change

It is now accepted that human activities have significantly altered the global climate through the production and emission of carbon dioxide (CO_2) and other greenhouse gases such as methane (which has a global warming potential (GWP) of approximately thirty times that of CO_2) and nitrous oxide (which has a GWP of approximately two hundred and seventy times that of CO_2).

At present global greenhouse gas (GHG) emissions continue to grow year on year accelerating the rate of climate change such that the period 2015-2019 is the warmest on record exceeding pre-industrial averages by 1.1°C with global emissions standing at 53.5 $GtCO_2e$[1] annually[2]. In order to mitigate the negative effects of climate change a target temperature increase limited to 1.5°C above pre-industrial levels has been proposed by the Intergovernmental Panel on Climate Change (IPCC) of the United Nations (UN). To meet this target a reduction of total emissions to 24 $GtCO_2e$ (44% of current emissions) is required by 2030 with a further reduction to less than 10 $GtCO_2e$ by 2050 (<18% of current emission)[3].

Current emissions production is unequally distributed in spatial and economic terms; however, it is closely correlated with economic advantage with wealthier nations producing the highest per-capita emissions, whilst within nations wealthier individuals produce the highest emissions[4]. At present rates, per capita emissions globally are 6.95 tCO_2e per annum, with a reduction required to 3.12 tCO_2e per person per annum by 2030. In Ireland per capita emissions stand at approximately 12.65 tCO_2e per annum. Thus a per capita

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[1] CO_2e or carbon dioxide equivalent means total emissions of all greenhouse gases expressed in terms of their equivalent amount of carbon dioxide that would produce the same amount of global warming.

[2] World Meteorological Organisation, *United In Science*, 2019.

[3] United Nations Environment Programme, *Emissions Gap Report 2018*, 2018.

[4] Michael J. Lynch et al., "Measuring the Ecological Impact of the Wealthy: Excessive Consumption, Ecological Disorganization, Green Crime, and Justice"*Social Currents*. 6.4 (2019): 377–395; Jonas Nässén et al., "Explaining the Variation in Greenhouse Gas Emissions Between Households: Socioeconomic, Motivational, and Physical Factors"*Journal of Industrial Ecology*. 19.3 (2015): 480–489.

reduction of emissions 75% of emissions per person is required in order to meet global targets for 2030.

Total GHG emissions in Ireland stand at 60.74 $MtCO_2e$ of which agriculture accounts for 20.23 $MtCO_2e$ (33.3%)[5]. Identifying the source of emissions on a per country and per sector basis is difficult due to the transnational nature of supply chains and the complex interrelation between waste products and feed stocks for differing industries. However, the Environmental Protection Agency (EPA) which is the agency responsible for the calculation and mitigation of Irish GHG emissions assumes the following sources in the calculation of Irish agriculture emissions; emissions from fertiliser application, ruminant digestion, manure management, agricultural soils and fuel used in agriculture/forestry/fishing. As such these emission figures account only for those direct emissions produced in the production of Ireland's agriculture sector and excludes the indirect "upstream emissions" required to produce the $11.2B USD[6] of imports to the Irish agriculture and food sectors of which the largest single component ($1.2B USD) is animal fodder. And so while it is useful to take a figure of 12.65 tCO_2e for emissions for each Irish person, in reality many of the emission we produce through our consumption are counted in other countries and so our emissions figures here are likely conservative.

1.3 Biodiversity and ecological collapse

In 2019 the Intergovernmental Panel on Biodiversity and Ecosystem Service (IPBES) published a wide-ranging report on the impact of human activity on animal and plant ecosystems. The report details that in the last fifty years, humans have caused severe degradation of almost all ecosystems, many of which are in danger of, or suffering from, total collapse. These effects include the alteration of 75% of all land area, the alteration of the environment in 66% of ocean area, the destruction of over 50% of the world's tropical forests, the loss of 85% of global wetlands, the loss of 50% of global coral and an average population decrease of 50% of wild vertebrate species in land, freshwater and sea. At present approximately 1 million species face extinction within decades[7].

The primary source of ecosystem loss is land use change for agriculture, however direct exploitation of natural ecosystems such as fishing, logging and alteration of ecosystems through pollution and climate change related effects is also having significant effects. Pollution through industrial sources and agriculture have strong negative effects on freshwater, soil and marine ecosystems. Plastic pollution in the marine and freshwater ecosystem is an emerging and increasing problem however, its exact effects on plant and animal life is not fully understood due to the early nature of scientific research in this area. IPBES reports that marine plastic pollution affects at least 267 species including 44% of seabird species and 43% of marine mammals. A recent meta-analysis of marine pollution suggests that reported levels of prevalence in different species relate primarily to the species for which research has currently taken place and that impacts for other species are likely to exist but at present are not described. Meanwhile a 2019 study has shown how microplastics impact on the growth of worms within the soil ecosystem[8]. It is worth noting

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[5] 'EPA 2019 GHG Emissions Projections Report' (2019), *EPA 2019 GHG Emissions Projections Report*, 2019.

[6] United Nations COMTRADE, "Ireland Trade Statistics" (United Nations, 2018).

[7] Sandra Díaz et al., *IPBES Global Assessment: summary for policy-makers* (United Nations, 2019).

[8] Anglia Ruskin University, "Microplastics stunt growth of worms"*PHYS.org.* , 2019.

that research by the WHO has so far failed to identify microplastic impacts on human health, however, the authors have highlighted the early nature of research into the subject[9].
Agriculture is the primary source of global biodiversity loss. The impacts of agriculture occur primarily through land-use change, the use of pesticides and fertilisers, through the alteration of soil diversity and through wastes and run-offs[10]. Whilst various meta-analyses of organic farming have identified increased levels of biodiversity on organic farms compared to "conventional" farming practices organic farms still have a significant negative impact on biodiversity and despite a narrowing gap in output[11] generally require greater land use than highly intensified farming methods[12].
Within the Irish context 67.35% of total land use is agricultural, of which 92% is grassland or rough grazing. Agriculture is present as a threat in 70% of Irish protected ecosystems of which in 35% it is classified as a high-pressure threat whilst at the same time 53% of water pollution cases are identified as resulting from agricultural practices[13]. Overall 91% of Irish protected habitats are indicated as having bad or inadequate protection for biodiversity, with this status improving in only 16% of cases. In almost all cases freshwater and marine habitats are indicated as having negative conservations status. Since 2006 Ireland has begun surveying species abundance, of those species surveyed since 2006 4% are indicated as now being extinct with at least a further 30% of species in either threatened (critically endangered, endangered or vulnerable) or near threatened categories[14]. Whilst global fishing stocks are overfished in 31%[15] of cases recent indications of Irish fish stocks indicate a tentative improvement in Irish Atlantic stocks in the period from 2009 to 2013 however note that at least 24% of fish stock continue to be overfished[14].

1.4 Inequality and social justice

Since the 1980s the world has seen a sharp rise in global wealth and income inequality with the most significant changes being the share of income and wealth change among the top 10% and top 1% of wealth groups[16]. Globally efforts to tackle climate change and biodiversity loss are significantly affected by inequality as the rich account for significantly higher levels of emissions through consumption and where wealth inequality fuels deforestation and land use change in order to provide food security for those in lower

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[9] Albert A. Koelmans et al., "Microplastics in Freshwaters and Drinking Water: Critical Review and Assessment of Data Quality"*Water Res*. May.155 (2019): 410–422.
[10] Alison Mclaughlin and Pierre Mineau, "Agriculture Ecosystems & Environment The impact of agricultural practices on biodiversity"*Agriculture. Ecosystems and Environment*. 55.95 (1995): 201–212.
[11] Lauren C. Ponisio et al., "Diversification practices reduce organic to conventional yield gap"*Proceedings of the Royal Society B: Biological Sciences*. 282.1799 (2015).
[12] S. J. Butler, J.A. Vickery, and K. Norris, "Farmland Biodiversity and the Footprint of Agriculture"*Science*. 315.5810 (2007): 381–384; D. G. Hole et al., "Does organic farming benefit biodiversity?"*Biological Conservation*. 122.1 (2005): 113–130; Mclaughlin and Mineau, "Agriculture Ecosystems & Environment The impact of agricultural practices on biodiversity"; Pytrik Reidsma et al., "Impacts of land-use change on biodiversity: An assessment of agricultural biodiversity in the European Union"*Agriculture, Ecosystems and Environment*. 114.1 (2006): 86–102.
[13] Environmental Protection Agency, *Ireland's Environment – An Assessment 2016*, 2016.
[14] Department of Arts Heritage and the Gaeltacht, *Ireland's 5th National Report to the Convention on Biological Diversity*, 2014.
[15] Food and Agriculture Organization, *The State of World Fisheries and Aquaculture* (Rome, 2016).
[16] Facundo Alvaredo et al., *World Inequality Report Executive Summary* (World Inequality Lab, n.d.).

wealth brackets[17]. Research has shown that globally the single biggest indicator for negative impact on climate change is net income[18]. At the same time global trade in agricultural products has a negative impact on the food security, livelihood and ecosystem of local communities in lower income exporting economies[19]. Meanwhile widescale reports of forced and low-wage labour managed by violent and exploitative criminal organisations in the production of commodity agricultural products are widespread throughout the globe.
Within the Irish context the top 10% of the population hold more than half the net wealth. Within urban centres the increase in rental property prices have driven a rapid increase in the cost of living. The national living wage technical group in Ireland have indicated that a minimum wage of €12.30 per hour for fulltime employment is required to maintain a basic standard of living[20]. Meanwhile 26,000 smaller farms in Ireland are indicated as being vulnerable to closure[21]. It is difficult to accurately classify the social impacts of rising inequality however it is possible to suggest that increased wealth concentration leads to higher levels of precarity for lower- and middle-income earners leading to negative social and quality of life indicators.

1.5 Understanding the climate change impacts of food production

Modern food production is characterised by highly globalised, intensified and specialised supply chains. The production of GHG emissions comes from a diverse range of sources including directly from agricultural production, production of agricultural inputs such as fertilizer and feed, transport, storage and waste. The balance of these inputs varies widely depending on the food produced, farming method and due to supply chain factors. It is useful in trying to understand the impact of food production on emissions to examine briefly the chief sources of these emissions. In Ireland it is estimated that of direct emission from agriculture (e.g. not including emissions related to remote production of feed or land use emissions from deforestation) 67% are accounted for by enteric fermentation and manure management whilst 30% are accounted for by the application of fertilisers to soil and the associated nitrogen cycle, with only 3% of emissions being accounted for by fuel and other uses[22]. This is typical of production systems that include high proportions of animal production. In systems of vegetable product production, the proportional mix of sources is much more varied. For example, in a study of tomato production in an unheated greenhouse in Spain, fertilizer use accounted for ~30% of GHG intensity, as did the production and maintenance of facilities, whilst equipment uses accounted for ~30%[23]. In

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[17] Sam Pizzigati, "Can an Unequal Earth Beat Climate Change?"*Inequality.org*. , n.d.; M. Graziano Ceddia, "The impact of income, land, and wealth inequality on agricultural expansion in Latin America"*Proceedings of the National Academy of Sciences of the United States of America*. 116.7 (2019): 2527–2532; Climate Equity Reference Project, *AFTER PARIS A CIVIL SOCIETY SCIENCE- AND EQUITY-BASED ASSESSMENT OF THE NDCS*, 2018.
[18] Nässén et al., "Explaining the Variation in Greenhouse Gas Emissions Between Households: Socioeconomic, Motivational, and Physical Factors."
[19] Díaz et al., *IPBES Global Assessment: summary for policy-makers*.
[20] Living Wage Technical Group, *LIVING WAGE Update 2019*, 2019.
[21] Environmental Protection Agency, *Ireland's Environment – An Assessment 2016*.
[22] EPA, *Ireland's Greenhouse Gas Emissions*, 2018.
[23] Marta Torrellas et al., "LCA of a tomato crop in a multi-Tunnel greenhouse in Almeria"*International Journal of Life Cycle Assessment*. 17.7 (2012): 863–875.

another study of tomato production in France ~50 of GHG was accounted for by water and fertilizer use, the greenhouse structure accounted for ~35%[24]. In a study of vegetable production for heated and unheated greenhouses differences in production methods account for vastly different ratios of emission production. For an unheated greenhouse with a GHG intensity of 0.24 kgCO_2e/kg emissions were accounted for by postharvest cooling (36%), refrigerated transport (24%), lighting (12%), plant propagation (11%). In the case of a heated greenhouse, which had a GHG intensity more than 10 times that of an unheated greenhouse, 91% of emissions were accounted for by heating and lighting[25].

1.6 Understanding waste in Ireland

Municipal waste in Ireland consists of three primary streams; recyclable municipal waste (green waste), municipal waste (black waste) and biodegradable municipal waste (brown waste). Since 2016 the EPA has tried to reduce landfill through the introduction of landfill levies. All Irish waste is either sent to recycling facilities, incineration in Ireland or landfilled. Of the 2,647 tonnes of municipal waste produced in 2016, 1,125 tonnes (43%) were directed to recycling, 811 tonnes (31%) was used incinerated and 711 (27%) was landfilled. The figure for landfill was reduced to 427 tonnes in 2019[26] and is intended to be reduced to 0 with the introduction of a second national incinerator in Cork. Black waste produced in Dublin is incinerated. Green waste is generally exported. In 2016 95% of plastic waste was exported to China, however since 2019 China will no longer accept EU plastic and so this has been diverted to other markets such as Cambodia, Indonesia, Malaysia and Vietnam about which environmental concerns exist. Brown waste is recycled in industrial composting facilities in Ireland.

Based on a 2018 waste characterisation survey carried out by the EPA in which the total waste stream was disposed of as 65% black, 24% green and 11% brown the actual waste character was 44% black, 27% green, 25% brown and 4% other. As such significant amounts of, primarily brown, waste is being miscategorised. However, as can also be seen the majority of green waste was correctly categorised. The restaurant sector accounted for 12% of municipal waste in Ireland, with the biggest components in black bins being organic waste (~30%), paper (22%), plastic (13%). In the green waste stream, the largest components were plastic (29%), cardboard (28%) and paper (14%). Of the waste included in this stream (4%) is accounted for by composites such as coffee cups. These are not currently recycled in Ireland. It is also worth noting that it is likely that most take-away packaging is not accounted for within the waste stream of restaurants, for example the waste stream for the general retail sector includes 4.7% composite materials such as coffee cups[27].

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[24] Sandra Payen, Claudine Basset-Mens, and Sylvain Perret, "LCA of local and imported tomato: An energy and water trade-off"*Journal of Cleaner Production*. 87.1 (2015): 139–148.

[25] Almudena Hospido et al., "The role of seasonality in lettuce consumption: A case study of environmental and social aspects"*International Journal of Life Cycle Assessment*. 14.5 (2009): 381–391.

[26] Environmental Protection Agency, *EPA Waste Data Release*, 2018.

[27] Clean Technology Centre, *Non-household Waste Characterisation Campaign*, 2018.

2 Methodology

The purpose of this report is to examine the impact of supply chain choices available to Irish food business. Recognising the complexity of supply chains for food products and the overlapping, but not necessarily dependent, challenges described above it is not possible to apply a single rating to products that describes their position on an axis with environmental or social benefit at one end and the opposite harm at the other. At the same time, the complexity of the supply chain, the varied nature of inputs and outputs from all the related processes and the unavailability of data mean it is not possible to produce exact values for the climate change, biodiversity or inequality impact of any one product.

In order to respond to these challenges this research uses a five-axis relative rating system with which to describe the impact of studies food options under the following headings; Climate Change, Ecosystem Use, Pollution, Human Impact and Cost. The factors that are taken into account for each of these headings are described below. It is worth noting however that these axes are not fully independent of each other nor can they be mapped completely to external effects such as species or habitat loss.

2.1 Rating System

2.1.1 Climate Change

Climate change indicates the contribution of the product to global warming through the production of CO_2 and other GHG emissions. Where possible the emissions rating includes the emissions associated with the change to the natural carbon cycle from land use alteration. Where possible emissions from waste product degradation is included in particular the emission of CH_4 (methane) and other high GWP gases.

2.1.2 Ecosystem Use

Ecosystem use indicates the required inputs from natural ecosystems to the production of the product. This includes land and water use, use of natural materials, and degradation of ecosystems through production processes (e.g. bottom trawling). High levels of ecosystem use map to negative effects for both climate change and biodiversity.

2.1.3 Pollution

Pollution indicates the impact of the outputs of the production and use of the product. This includes the production of plastic and chemical waste and run-off from agriculture. High levels of pollution map to negative impacts for biodiversity and in some cases on local human populations.

2.1.4 Human Impact

Human impact indicates the effects of the production processes on human quality of life. This includes production of inequality, use of coercive or violent labour practices or damage to communities or health of communities by production practices. This does not include any known or potential health risk to the users of products.

2.1.5 Cost

This indicates the relative cost to the food business of the product.
Each business is acutely aware of the costs of sourcing the materials used in their production and so this section is included only as a means of comparison. The costs here are rough indicated minimum prices based on a brief survey of wholesale suppliers in Dublin and will not necessarily reflect those paid by food business.

2.2 Research Methods

The research contained within this report consists of secondary research and meta-analysis of existing research. Meta-analysis describes combining the output of existing research in order to create a more complete picture of the research subject. The use of wide-ranging studies and meta-analysis is intended to account for the presence of outlier data for any object of study.
The research used for the compilation of this report is gathered from a variety of sources which includes governmental research (govt. departments, state agencies e.g. EPA), intergovernmental agencies (e.g. World Meteorological Organisation (WMO), IPBES, IPCC, Food and Agriculture Organisation (FAO)), civil society groups and non-governmental agencies (e.g. TASC, World Inequality Lab, Climate Equity Reference Project) and academic institutions. Where possible research that has been funded commercially has been excluded. As different research methodologies, geographical and temporal factors produce different results relative values for each heading are explained in each case with reference to source material. Likewise, given that specific research for each product within an Irish context is not always readily available results for similar products are taken from alternative but similar contexts where data is available. In each case these assumptions are indicated.
In the choice of product for comparison within this study, the research has examined commonly used and widely available options to Irish food businesses. Whilst there exist in some cases small scale alternative production methods that may offer benefits on one or more of the axes of interest, these have been omitted from the main research and are handled within the discussion at the end of this report.

3 Case Study – Avocado

The growth of avocado consumption has become synonymous with the development of a globalised transnational food culture. Once ever present on café breakfast and brunch menus, recently a number of food businesses have removed avocados from their menus either seasonally or completely citing environmental and labour concerns. This case study examines the relative impact of avocado compared to other common café items and other common daily practices.

3.1 Avocado Production

Avocados are grown primarily in South and Central America. The biggest global producers are Mexico (34% of total global supply), Dominican Republic (11%), Peru (8%), Indonesia (6%), Colombia (5%)[28]. In the Irish market most avocados are imported from the Netherlands which is Europe's biggest importer of bulk avocado for re-export and which imports avocados primarily from Peru, Chile, South Africa, Mexico, Spain, Kenya and Israel[29] depending on season, crop yield and price.

3.2 Avocado Footprint

A recent meta-analysis of different fresh fruit food types places the carbon footprint of avocado at 1.30 kgCO_2e/kg whilst a similar life-cycle analysis (LCA) of avocados from farm (in Chile, Israel, Peru, Spain and South Africa) to point of sale in Switzerland produced similar results ranging in values of 0.81 kgCO_2e/kg (Spain) to 1.98 kgCO_2e/kg (Chile) with values of 1.71 kgCO_2e/kg (Peru), 1.69 kgCO_2e/kg (South Africa) and 1.65 kgCO_2e/kg (Mexico) for the other main exporters of avocado to Ireland[30,31]. In terms of land-use-change related carbon emissions, where avocado plantations replace existing forestry as is the case in Mexico, Peru, Chile it can be suggested that plantations store less carbon than natural forestry[32] and thus there is an additional GHG impact. In the case of plantations replacing lower carbon sink land use types the existence of plantations can contribute to carbon storage. In most cases avocado transport to both The Netherlands and Ireland is by sea and road freight, in these cases it can be assumed, through comparison with studies for other crops, that transport related emissions account for a maximum of 30%[33,34].

Avocados are grown in a diverse range of climatic and geographic areas and as such ecosystem impacts vary locally. However, the primary ecosystem impacts of avocados are

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[28] FAOSTAT, "Crops" (UNited Nations Food and Agriculture Organisation, n.d.).

[29] Statistics Netherlands (CBS), *Netherlands second largest avocado importer worldwide*, n.d.

[30] Franziska Stoessel et al., "Life Cycle Inventory and Carbon and Water FoodPrint of Fruits and Vegetables: Application to a Swiss Retailer"*Environmental Science & Technology*. 46.6 (2012).

[31] A recent and widely reported analysis of Avocados for sale in the UK conducted by Carbon Footprint Ltd on behalf of food packaging company It's Fresh produced a value of 0.85 kgCO_2e for two avocados, which translates to 1.57 kgCO_2e/kg based on a 270g avocado. As the research behind this number is not published it is omitted here.

[32] J. A.B. Ordóñez et al., "Carbon content in vegetation, litter, and soil under 10 different land-use and land-cover classes in the Central Highlands of Michoacan, Mexico"*Forest Ecology and Management*. 255.7 (2008): 2074–2084.

[33] See [25] above.

[34] Annika Carlsson-Kanyama, "Climate change and dietary choices - how can emissions of greenhouse gases from food consumption be reduced?"*Food Policy*. 23.3–4 (1998): 277–293.

land use and deforestation (primarily in forest ecosystems such as Mexico, Colombia, and Brazil) and water use (primarily in Peru, Israel, South Africa, Spain and Chile). There is limited academic research detailing the full extent of avocado related deforestation however, there is sufficient media reporting of the problem in Mexico[35]. It is possible to assume similar land use impacts in other exporting countries such as Brazil, Colombia and Peru. In dryer climates avocado cultivation is associated with high levels of water stress[36].

In terms of pollution there are no significantly reported indicators for avocado production other than high levels of pesticide use in avocado plantations indicated in a number of studies[37].

The human impact of avocado production is varied locally. In Mexico there is widescale reporting of organised criminality in avocado production. Elsewhere avocado production is typical of agriculture in developing countries with an increasing proportion of large plantations to smaller holdings. In larger plantations low-wage labour and wealth concentration is a contributor to growing inequality.

3.3 Avocado in context

3.3.1 Serving size

As can be seen from the above data avocado production is part of an increasingly globalised system of production that impacts in the areas of climate change, biodiversity and inequality. It is necessary however to consider the avocado in the context of other commonly used items within Irish food business.

Taking the GHG figure of 1.71 $kgCO_2e/kg$ for avocado[38] and an avocado average weight of 270g the GHG of a single serving of half an avocado is 0.23 $kgCO_2e$.

3.3.2 Coffee

An average cup of black coffee or tea (250g) has a GHG emission of 0.021 $kgCO_2e$ assuming water is heated only as required[39]. However, a similar sized dairy milk-based coffee such as a latte has a GHG emission of 0.34 $kgCO_2e$ (148% of an avocado serving)[40]. Switching to a non-dairy milk such as almond or coconut reduces this figure to 0.128 $kgCO_2e$[41,42] (56% of an avocado serving).

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[35] Will Tucker, "Taking the Deforestation Out of Avocados"*Ecosystem Marke*. , Aug. 2016.

[36] "Green Gold: Are Your Avocados Draining A Community's Drinking Water? | Civil Eats"*Civil Eats*. , Sep. 2014; and see [30] above.

[37] Sophie Graefe, Jeimar Tapasco, and Alonso Gonzalez, "Resource use and GHG emissions of eight tropical fruit species cultivated in Colombia"*Fruits*. 68.4 (2013): 303–314; and see [30] above.

[38] This figure is taken as the value for Peruvian avocados in [30] above. An additional sea freight and associated storage step in the transportation to Ireland from The Netherlands suggest this figure is conservative.

[39] Eva Brommer, Britta Stratmann, and Dietlinde Quack, "Environmental impacts of different methods of coffee preparation"*International Journal of Consumer Studies*. 35.2 (2011): 212–220. A recent German LCA of different coffee machine usage options places the figure for a single cup of coffee at five times this (0.102 $kgCO_2e$) figure for a coffee machine of average efficiency. An accurate figure is likely between the two values.

[40] Based on UK electricity consumption which has a roughly similar albeit slightly better carbon intensity to Irish electricity production, Mike Berners-Lee, *How Bad Are Bananas The Carbon Footprint of Everything.* (Vancouver: Profile Books, 2010).

[41] Stephen Clune, Enda Crossin, and Karli Verghese, "Systematic review of greenhouse gas emissions for different fresh food categories"*Journal of Cleaner Production*. 140 (2017): 766–783.

[42] Carboncloud Ab, *CLIMATE FOOTPRINT OF ENRICHED OAT DRINK AMBIENT* (Göteborg, 2019). A recent independently commissioned LCA of Oatly oat-based milk replacement gives a figure of 0.35 $kgCO_2e/kg$ which is lower than the figure of 0.42 $kgCO_2e/kg$ used above for coconut or almond milk taken from [33] above.

Similar to avocado production coffee is associated with deforestation in most areas of cultivation[43] and in most cases is associated with high pesticide use[44]. Coffee has long been widely associated with unequal ownership, work practices and exploitative policies from an individual farm level to a global ("North-South") trade level. These trade practices have historically led to vastly increased levels of inequality between producers (farmers, cooperatives) and consumers (Irish food business) and within coffee producing economies between lower level farmers, or farm labourers and local agents, distributors, owners etc. Coffee can be suggested as having roughly similar impacts under the headings of Ecosystem Use, Pollution, and Inequality to avocado production. However, unlike avocado production, due to the high value commodity trading of different coffees there currently exists a more direct market link between producers (farmers, cooperatives) and consumers as such there exists greater choice for selection of coffee that doesn't increase deforestation, that uses natural pest control or agricultural methods and that provide a greater share of the extracted economic value to the producer.

3.3.3 Other Fruits and Vegetables

Comparing an avocado other fruit and vegetable options demonstrates however, that avocado is a relatively high GHG emitting vegetable crop. In a survey of LCAs[45] all field grown vegetables produced an average of 0.47 kgCO_2e/kg based on 140 research values (27% of avocado), all field grown fruit produced an average of 0.50 kgCO_2e/kg based on 250 research values (29% of avocado) and all passively heated greenhouse grown vegetables produced an average of 1.02 kgCO_2e/kg based on 15 research values (60% of avocado). However, when compared to vegetables grown in heated greenhouses what becomes clear is that many vegetable products exceed the emissions of avocados. In the same LCA survey the average emission of greenhouse grown vegetables was 2.81 kgCO_2e/kg based on 53 research values (164% of avocado). In particular vegetables such as courgette (1.77 kgCO_2e/kg), cucumber (2.23 kgCO_2e/kg), tomato (2.69 kgCO_2e/kg)[46], lettuce (3.15 kgCO_2e/kg)[47] were found to exceed [48] the GHG emission of avocado. These values are reflected in a report on the LCA of fresh produce to Swiss retailers which also includes asparagus as the most emitting product with an average figure of ~9 kgCO_2e/kg[49]. It is not possible to provide an analysis of the relationship of avocado to the wide range of other fruit and vegetable products in terms of deforestation. However, a number of noteworthy examples are worthy of mention in this case, namely, deforestation for animal

[43] Peter Baker, "Global Coffee Production and Land Use Change"*ICO World Coffee Conference*. 2.March (2014): 1–4; M. Luisa Martínez et al., "Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico"*Forest Ecology and Management*. 258.9 (2009): 1856–1863.

[44] A C Bellotti, C Cardona, and S L Lapointe, "TRENDS IN PESTICIDE USE IN COLOMBIA AND BRAZIL'""*J. Agric. Entomo!* 7.December 1988 (1990): 191–201.

[45] See [41] above.

[46] Further detailed analysis of emissions factors for different tomato production systems are contained later in this report.

[47] See [25] above, A detailed analysis of different lettuce production methods shows a high range of deviation for GHG emissions from >3.5 for heated UK grown lettuce in winter to <0.5 for UK greenhouse grown in summer.

[48] See [41] above.

[49] See [30] above. The high value achieved for asparagus is accounted for through the contribution of air freight from Mexico and Peru. In the case of asparagus from Morocco, Slovenia and Switzerland (mainly road freight) and Peru (sea freight) the figures are <2 kgCO_2e/kg.

feed crops and deforestation[50] for the production of palm oil[51], both of which are associated with biodiversity loss through, land-use change and pesticide use. There is also widespread reporting that in both cases there exists significant unequal labour and ownership practices and displacement of communities, however, there exists counter narratives of local community members who have benefited economically from new forms of agriculture[52]. Recent reporting by Oxfam indicates the presence of both unequal and unsafe working practices across imported food supply chains[53].

3.3.4 Eggs

Based on a survey of 38 research values the greenhouse gas emission of eggs is 3.46 $kgCO_2e/kg$ (202% of avocado). There is a high deviation in reported GHG emissions from eggs with values ranging from 6 $kgCO_2e/kg$ to 1.2 $kgCO_2e/kg$ depending on LCA methodology and farming practice. However, based on the number of studies a median figure is considered satisfactory. Taking this figure and an average egg weight of 60g a serving of two eggs produces a GHG of 0.42 $kgCO_2e$ (182% of a serving of avocado).

Animal farming in Ireland is associated with incidents of effluent pollution and atmospheric pollution of ammonia, however, this is regulated by the EPA. Nevertheless, studies by the EPA[54] and others[55] have indicated significant instances of pollution and ecosystem degradation. Animal farming in Ireland is generally operated in a mix of small and larger holdings. Smaller holdings generally are owner operated and as such farmgate earnings are generally retained by the producer, however, farm gate to consumer supply chains are generally highly centralised and represent greater levels of economic disparity between low-paid and higher paid workers.

3.3.5 Cheese and Meat

When compared with cheese and meat there is a greater divergence in the amount of GHG emissions. Based on a survey of 38 research values cheese produces 8.86 $kgCO_2e/kg$ (518% of avocado), UK pork produces 6.0 $kgCO_2e/kg$ (351% of avocado), UK lamb produces 25.84 $kgCO_2e/kg$ (1511% of avocado) and UK beef produces 25.76 $kgCO_2e/kg$ (1506% of avocado)[56], whereas Irish beef produces up to 40 $kgCO_2e/kg$ (2339% of avocado) depending on production differences[57].

3.3.6 Non-food context

It may also be useful to give some context of the emissions described above in terms of non-food items. For example, a return flight from Dublin to London produces 215 $kgCO_2e$[58]. This is equivalent to 934 servings of avocado. A pair of Levi Strauss 501 jeans

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[50] Daniel Nepstad et al., "Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains"*Science*. 344.6188 (2014): 1118–1123.

[51] The Intergovernmental Panel on Climate Change, *Climate Change and Land*, 2019.

[52] For one example amongst others see: Mendelson Lima, Margaret Skutsch, and Gerlane de Medeiros Costa, "Deforestation and the social impacts of soy for biodiesel: Perspectives of farmers in the south Brazilian Amazon"*Ecology and Society*. 16.4 (2011).

[53] Rachel Wilshaw and Robin Willoughby, *Workers ' rights in supermarket supply chains* (Oxfam GB, 2019).

[54] See [13] above.

[55] Kevin Parris, "Impact of agriculture on water pollution in OECD countries: Recent trends and future prospects"*International Journal of Water Resources Development*. 27.1 (2011): 33–52.

[56] See [41] above. Further detailed analysis of the GHG of meat products is contained later in this report.

[57] J. W. Casey and N. M. Holden, "Greenhouse gas emissions from conventional, agri-environmental scheme, and organic irish suckler-beef units"*Journal of Environmental Quality*. 35.1 (2006): 231–239.

[58] Based on calculations provided by https://www.atmosfair.de/en/offset/flight.

produces 33.4 $kgCO_2e$, equivalent to 145 serving of avocado[59]. Taking current Irish average individual emissions of 12,650 $kgCO_2e$ a weekly serving of avocado represents 11.96 $kgCO_2e$ or <1/1,000th of total emissions whereas a return trip to London represents ~1/60th of yearly total emissions.

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[59] Tara Hackett, "A Comparative Life Cycle Assessment of Denim Jeans and a Cotton T-Shirt: The Production of Fast Fashion Essential Items From Cradle to Gate"University of Kentucky, 2015.

4 Comparative Analysis – Protein

Whilst there is no single defined combination of nutrients that constitute a healthy diet[60] there is significant evidence to suggest various minima and maxima for the intake of macronutrient and nutrient categories. Of these, dietary protein is an essential component required for the growth and maintenance of a healthy body. The protein requirement is considered as the minimum protein required to develop and maintain healthy bodily function. Notwithstanding the differences in body types and activities of individuals it is possible to suggest the following protein requirements for individuals; for an individual of 55kg body weight a daily requirement of 46g of protein, for an individual of 65kg of a daily requirement of 54g of protein[61].

Protein consumption in Ireland, as generally within richer nations, far exceeds the daily protein requirement. A 2001 report on Irish nutrition recorded an average daily protein intake of 84.4g of which 37% (31g) was constituted from meat and meat products, 14% (12g) was constituted from bread, 11% (9g) was constituted from dairy products and 19% (16g) was constituted from other sources excluding potatoes (6%), fish (5%), vegetables (4%), and cakes & biscuits(4%)[62]. The United Nations Food and Agriculture Organisation suggest that this value has increased to 110g for 2013[63]. Meanwhile, anecdotal evidence suggests a trend for increased prevalence of high-protein foods such as protein bars or protein enriched products.

In order to understand the impact of various protein choices available to Irish food businesses this report will examine the impact of the following products; Low-intensity beef production (typical of Irish primarily grass-fed beef production), intensive beef production (typical of European and some Irish beef production), EU chicken production, Irish dairy production, fish production, soya and pulse production. Where possible the analysis will be normalised by unit of protein rather than unit of food product weight.

4.1 Low intensity beef

4.1.1 Climate Change

Low intensity beef production typical to Ireland is generally a mix of grass a feed fed cattle[64]. Due to different farming practices and assessment methodologies, e.g. farm-to-gate, farm-to-slaughterhouse, etc, there is some disagreement on total GHG emission for low intensity beef production. One 2017 meta-analysis estimates median UK beef production at 26.57

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[60] Walter Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems"*The Lancet*. 393.10170 (2019): 447–492; Global Panel on Agriculture and Food Systems for Nutrition, *Food Systems and Diets: Facing the challenges of the 21st century* (London, 2016).

[61] Report of a Joint WHO/FAO/UNU Expert Consultation, *Protein and amino acid requirements in human nutrition.World Health Organization technical report series.*, 2007.

[62] Irish Universities Nutrition Alliance, *North/South Ireland Food Consumption SurveyPublic Health Nutrition*. (SafeFood, 2001).

[63] FAOSTAT, "Food Balance Sheet" (UNited Nations Food and Agriculture Organisation, n.d.).

[64] P. A. Foley et al., "Whole-farm systems modelling of greenhouse gas emissions from pastoral suckler beef cow production systems"*Agriculture, Ecosystems and Environment*. 142.3–4 (2011): 222–230.

$kgCO_2e/kgBFM$[65,66] based on 26 research values. Studies specific to Irish production techniques such as a 2006 estimate which excluded post farmgate emissions estimate a value of 21.8 $kgCO_2e/kgBFM$[67]. A further 2011 study, which excluded both post-farm emissions and machine energy use, estimates a value of 33.23 $kgCO_2e/kgBFM$[68]. In 2013 the UN FAO produced the Global Livestock Environmental Assessment Model (GLEAM) designed to account for post-farm emissions and energy usage and which estimates Irish beef production emissions intensity at 39.86 $kgCO_2e/kgBFM$[69]. Taking the most recent value for bone free meat and converting this to kilograms of protein using a conversion factor of 0.206 kg(protein)/kgBFM[70] gives 193.48 gCO_2e/kg(protein). These figures do not account for the potential sequestration of carbon by land returned from agricultural to wild use and are therefore likely conservative.

4.1.2 Ecosystem Use

Irish land use is primarily configured for agriculture with 67.35% of total land use maintained for agriculture, of which 92% is grassland or rough grazing. Agriculture is present as a threat in 70% of Irish protected ecosystems of which in 35% it is classified as a high-pressure threat[71]. Numerous studies have indicated the impact of agricultural land use as a major contributor to biodiversity loss within Ireland and more broadly within the EU[72]. Additionally, feed supplies for low intensity beef farming are associated with biodiversity loss.

4.1.3 Pollution

The primary source of pollution deriving from low intensity beef production in Ireland is related to agricultural run-off and the impacts of this on water course and freshwater ecosystems. This has been identified as a significant source of damage to freshwater and soil ecosystems[73]. At the same time 53% of water pollution cases are identified as resulting

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[65] kgBFM is kilogram of bone free meat.

[66] See [41] above.

[67] Casey and Holden, "Greenhouse gas emissions from conventional, agri-environmental scheme, and organic irish suckler-beef units." converted value based on a value of 10.57 $kgCO_2e/kgLW$ (live weight) using a conversion factor of 0.485 BFM to LW from [41] above.

[68] Foley et al., "Whole-farm systems modelling of greenhouse gas emissions from pastoral suckler beef cow production systems." converted value based on a value of 23.1 $kgCO_2e/kgCW$ (carcass weight) using a conversion factor of 0.695 CW to LW from [41] above.

[69] FAO, *Greenhouse gas emissions from ruminant supply chains*, 2013. converted value based on a value of 23.1 $kgCO_2e/kgCW$ (carcass weight) using a conversion factor of 0.695 CW to LW from [33] above.

[70] Alejandro D. González, Björn Frostell, and Annika Carlsson-Kanyama, "Protein efficiency per unit energy and per unit greenhouse gas emissions: Potential contribution of diet choices to climate change mitigation"*Food Policy*. 36.5 (2011): 562–570.

[71] See [13] above.

[72] Barry J. McMahon et al., "Interactions between livestock systems and biodiversity in South-East Ireland"*Agriculture, Ecosystems and Environment*. 139.1–2 (2010): 232–238.

[73] B. Ulén et al., "Agriculture as a phosphorus source for eutrophication in the north-west European countries, Norway, Sweden, United Kingdom and Ireland: A review"*Soil Use and Management*. 23.SUPPL. 1 (2007): 5–15; Cathal Buckley and Patricia Carney, "The potential to reduce the risk of diffuse pollution from agriculture while improving economic performance at farm level"*Environmental Science and Policy*. 25.January (2013): 118–126; S. I. Heaney et al., "Impacts of agriculture on aquatic systems: Lessons learnt and new unknowns in Northern Ireland"*Marine and Freshwater Research*. 52.1 (2001): 151–163.

from agricultural practices[74]. Additionally, pesticide use in is a significant polluting factor in all but organic use cases[75].

4.1.4 Social Impact

Animal farming in Ireland is generally operated in a mix of small and larger holdings[76]. Smaller holdings generally are owner operated and as such farmgate earnings are generally retained by the producer, however, farm gate to consumer supply chains are generally highly centralised and represent greater levels of economic disparity between low-paid and higher paid workers. Generally animal agriculture plays a significant role in supporting rural communities in Ireland.

4.1.5 Cost

A minimum cost for good quality Irish beef steak mince is estimated at 8.50€/kg.

4.2 Intensive beef

4.2.1 Climate change

Intensive beef production which is common in throughout Europe and to a lesser extent in Ireland requires a greater level of feed provision that low intensity grass fed beef production. One survey of EU beef LCA emission values estimates a median GHG intensity of 24.96 kgCO_2e/kgBFM[77]. In one 2018 study of Italian cattle production comparing four systems of increasing intensively from grass/grain mix (present in Ireland) to a grain only barn based fattening system (not generally present in Ireland) the less extensive system had an emission intensity of 58 kgCO_2e/kgBFM whereas the more intensive system 36.33 kgCO_2e/kgBFM[78]. Contrary to this, a 2006 paper, suggests that intensive beef production in Ireland can increase emissions intensity to 23.21 kgCO_2e/kgBFM from 21.8 kgCO_2e/kgBFM, whilst a UK comparison of production methods shows a higher GHG emission for intensive suckler production than less intensive organic production but a further reduction for less intensive conventional production models[79]. However, recent research from the UN FAO GLEAM estimates 27.97 kgCO_2e/kgBFM for grassland systems, reducing to 25.61 kgCO_2e/kgBFM for mixed systems and further reducing to 16.85 kgCO_2e/kgBFM for feedlot systems. Further research in 2017 suggest grass fed production models have generally higher GHG emissions per unit product[80]. In both the more recent studies intensive farming methods display a reduction of GHG intensity to ~61% of that of grassland systems. It is, however, difficult to state with certainty the extent to which intensification of beef production increase or reduces GHG intensity.

4.2.2 Ecosystem Use

Intensive farming by definition uses less land than extensive farming for the same production of product. This reduction in land use at the site of production is offset however

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[74] See [13] above.

[75] A.G. Williams, E. Audsley, and D.L Sandars, *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.Main Report. Defra Research Project*. , 2006.

[76] See [13] above.

[77] See [41] above.

[78] Andrea Bragaglio et al., "Environmental impacts of Italian beef production: A comparison between different systems"*Journal of Cleaner Production*. 172 (2018): 4033–4043 converted value based on values of 26.3 and 17.6 kgCO_2e/kgLW (live weight) using a conversion factor of 0.485 BFM to LW from [33] above.

[79] See [75] above.

[80] Michael Clark and David Tilman, "Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice"*Environmental Research Letters*. 12.6 (2017).

by the need for land use elsewhere in order to produce feedstock. In fact, livestock production is the single biggest driver of habitat loss globally with the primary driver being pasture and feedstock for intensive beef production[81]. Given that the growth of feedstock production occurs primarily in areas of high biodiversity such as the amazon basin intensive animal agriculture is associated with significant negative impacts on forest and soil ecosystems[82].

4.2.3 Pollution

The primary local sources of pollution deriving from intensive beef production is related to agricultural run-off similar to that of less intensive production methods with similar impacts on water course and freshwater ecosystems. A number of studies have shown a somewhat reduced potential for eutrophication and acidification from more intensive beef production systems[83], whilst other studies have indicated the specific impact of local conditions that suggest difficulty in making accurate comparisons[84]. Pesticide pollution levels are reported as broadly similar to less intensive production in a survey of UK production methods[85].

4.2.4 Social Impact

Animal farming in Ireland and Europe generally operated in a mix of small and larger holdings[86]. Smaller holdings generally are owner operated and as such farmgate earnings are generally retained by the producer, however, farm gate to consumer supply chains are generally highly centralised and represent greater levels of economic disparity between low-paid and higher paid workers. Generally animal agriculture plays a significant role in supporting rural communities. The production of some animal feed products such as soy is associated with unequal labour practices and increased levels of inequality (despite macro-level poverty reduction) and destruction of indigenous habitats[87].

4.2.5 Cost

A minimum cost for Irish beef steak mince is estimated at 6€/kg.

4.3 EU Chicken

4.3.1 Climate change

Chicken production in Ireland which is typical of EU production is generally high intensity production associated with high density containment of large numbers of animals. A meta-analysis of chicken production based on 95 research values indicates a mean GHG emission intensity of 3.12 $kgCO_2e/kgBFM$[88]. This value is broadly consistent with a UK report which estimated conventional production at 4.57 $kgCO_2e/kgBFM$, and which indicated an increase in GHG intensity to 5.48 $kgCO_2e/kgBFM$ for free-range (non-organic) and 6.68

[81] Brian Machovina, Kenneth J. Feeley, and William J. Ripple, "Biodiversity conservation: The key is reducing meat consumption"*Science of the Total Environment*. 536 (2015): 419–431.
[82] See [7] and [50] above.
[83] See [78] and [80]
[84] See [75] above.
[85] See [75] above.
[86] See [13] above.
[87] Diana Weinhold, Evan Killick, and Eustaquio J. Reis, "Soybeans, poverty and inequality in the Brazilian Amazon"*World Development*. 52 (2013): 132–143; Nepstad et al., "Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains"; William F Laurance, "Habitat destruction: death by a thousand cuts - Oxford Scholarship" (2010): 73–87.
[88] See [41] above.

$kgCO_2e/kgBFM$[89] for organic production. A more recent LCA of EU production produced a statistically similar value of 3.62 $kgCO_2e/kgBFM$, whilst a 2006 UK study estimated a value of 4.75 $kgCO_2e/kgBFM$ and a 2012 study in France estimated a value of 4.11 $kgCO_2e/kgBFM$[90]. Taking the mean value for bone free meat and converting this to kilograms of protein using a conversion factor of 0.188 kg(protein)/kgBFM gives 21.9 gCO_2e/kg(protein).

4.3.2 Ecosystem Use

Chicken farming is highly intensive and as such requires little land at the site of production in order to produce high levels of food output. Chicken production generally uses a small fraction of land comparted to intensive beef production and a significantly smaller fraction compared to low-intensity beef production[91]. Importantly chicken converts 20% of feed protein to edible protein compared with 4% for beef and as such land-use impacts of feed production are significantly lower than for beef production[92].

4.3.3 Pollution

Chicken farm pollution is primarily related to agricultural runoff. A UK study of production methods estimates eutrophication and acidification to be approximately one third of that of beef production[93]. A further study shows similar ratios for acidification and an even small (~one tenth) ration for eutrophication. However, in another review of LCAs a wide-ranging disparity of eutrophication and acidification figure was present[94]. Similar levels of pesticide use for feed production are present as in the cases of beef production.

4.3.4 Social Impact

Chicken farming in Ireland and Europe is more highly centralised than ruminant livestock production. Therefore, it represents greater levels of economic disparity between low-paid and higher paid workers. Generally animal agriculture plays a significant role in supporting rural communities. The production of some animal feed products such as soy is associated with unequal labour practices and increased levels of inequality (despite macro-level poverty reduction) and destruction of indigenous habitats[95].

4.3.5 Cost

A minimum cost for chicken is estimated at 7.40 €/kg for chicken breast fillets.

4.4 Irish dairy

4.4.1 Climate Change

Irish dairy production is generally typified by grass fed production. A survey of LCAs of milk production in the Ireland and the UK based on 35 research values estimates a mean value of 1.26 $kgCO_2e/kg$. When accounting for all EU dairy LCAs based on 175 research values

[89] See [75] above.

[90] Sara González-García et al., "Life Cycle Assessment of broiler chicken production: a Portuguese case study"*Journal of Cleaner Production*. 74 (2015) converted values based on values of 3.66 and 3.17 $kgCO_2e/kgCW$ using a conversion factor of 0.77 BFM to CW from [41] above.

[91] Durk Nijdam, Trudy Rood, and Henk Westhoek, "The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes"*Food Policy*. 37.6 (2012): 760–770.

[92] Tiim Searchinger et al., *Creating a Sustainable Food Future: Final Report*, 2019.

[93] See [75] above.

[94] See [90] above.

[95] See [87] above.

estimates a mean value of 1.32 $kgCO_2e/kg$[96,97]. Assuming the value for UK and Irish dairy and normalizing for protein content based on a protein content of 0.032 kg(protein)/kg gives a value of 39.38 $kgCO_2e$/kg(protein).

4.4.2 Ecosystem Use

As for low-intensity beef.

4.4.3 Pollution

As for low-intensity beef.

4.4.4 Social

As for low-intensity beef.

4.4.5 Cost

A litre of whole Irish milk is estimated 0.85 €/kg.

4.5 Fish

4.5.1 Climate change

Fish production consists of a wide variety of practices covering scales from vast industrial trawling, through line fishing to hand picking of shallow water species. These practices are distributed geographically at global, oceanic, regional and national scales. Since 1985 the global share of aquaculture as a percentage of total production of aquatic animals has risen from <20% to ~45% in 2014. An LCA meta-analysis of fish estimates a mean GHG intensity of 4.41 $kgCO_2e/kg$ for all species (excluding shellfish) based on 148 research values. There is however a large discrepancy in values estimated at a per species level ranging from herring (1.17), pollock (1.65), mackerel (2.00), tuna (2.6), whiting (2.66), haddock (3.37), sea bass (3.55), salmon (3.76), cod (3.49), mussels (7.54), cephalopods (8.07), hake (8.98), prawns (14.85), lobster (27.8). Disparity in energy use is generally a result of differences in fuel consumption for different fishing methods and varies by species and location. One survey okn energy use in marine fisheries estimates a variation from from 0.1 l(fuel)/kg for Irish mackerel, herring and whiting to 4.4 l(fuel)/kg for Italian shrimp and hake[98], whilst additional research indicates 9 l(fuel)/kg for Norwegian lobster trawling. In another survey of LCAs aquaculture also displayed high levels of disparity with a range of GHG intensity values of ~1.6-15 $kgCO_2e/kg$ with land-based aquaculture (turbot, trout, shrimp, etc.) having higher GHG intensity than marine cage-based system (salmon, seatrout, seabass). Given the high level of disparity the mean value of 4.4 $kgCO_2e/kg$ appears as an appropriate value. Normalizing for protein content based on a conversion factor of 0.207 kg(protein)[99]/kgBFM gives 21.26 $kgCO_2e$/kg(protein).

4.5.2 Ecosystem Use

Marine capture fisheries are by definition direct extraction of ecosystem resources. North-east Atlantic fish stocks for many species including Atlantic salmon, trout, smelts, European plaice, halibut, sole and other flounders, Atlantic cod, blue whiting, haddock, pollock, whiting and hake range from fully exploited to depleted[100]. At the same time whilst there is

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[96] The same research estimates values of 8.55 $kgCO_2e/kg$ for cheese and 11.52 $kgCO_2e/kg$ for butter.

[97] See [41] above.

[98] James F. Muir, *FUEL AND ENERGY USE IN THE FISHERIES SECTOR Approaches, inventories and strategic implications*, vol. 0 (Food and Agriculture Organisation of the United Nations, 2015).

[99] See [75] above.

[100] FAO, *General situation of world fish stocksReview of the state of world marine fishery resources*. (UNited Nations Food and Agriculture Organisation, 2015).

a range of reported impacts of fishing methods[101], particularly trawling on the marine ecosystem, counter evidence suggests in particular environments the disturbance of the marine bed increase overall fish numbers through nutrient release and encouragement of soft body organisms[102]. Whilst land based aquaculture has land use impacts and cage based has impacts within the marine ecosystem the primary ecosystem input is through production of feedstock. Aquaculture converts 18% of feed protein to edible protein (compared with 4% for beef and 20% for chicken)[103].

4.5.3 Pollution

Whilst there is limited research associating polluting activities with fish capture aquaculture is associated with the production of a number of negative effects including eutrophication of surrounding waters and emission of harmful outputs from pest control and antibiotic use[104].

4.5.4 Social Impact

Fishing in Ireland and Europe is generally operated in a mix of small and larger operations. In each case the capital required for fishing activity tends towards centralisation of ownership and unequal distribution of earnings from production. There are continued and significant reports of coerced labour, slavery and illegal work practices within the Irish fishing fleet[105]. Landing to consumer supply chains are generally highly centralised and represent high levels of economic disparity between low-paid and higher paid workers. However, fishing plays a role in supporting particular rural communities. The production of some aquafeed products such as soy is associated with unequal labour practices and increased levels of inequality (despite macro-level poverty reduction) and destruction of indigenous habitats[106].

4.5.5 Cost

To be filled in.

4.6 Soy and pulse

4.6.1 Climate Change

It is necessary at the outset of this section to contextualise the world market for soya beans. Globally only 6%[107] of soya bean production is used for human consumption with the

[101] Frode Olsgard et al., "Effects of bottom trawling on ecosystem functioning"*Journal of Experimental Marine Biology and Ecology*. 366.1–2 (2008): 123–133; J. G. Hiddink, S. Jennings, and M. J. Kaiser, "Indicators of the ecological impact of bottom-trawl disturbance on seabed communities"*Ecosystems*. 9.7 (2006): 1190–1199.

[102] P. Daniel van Denderen, Tobias van Kooten, and Adriaan D. Rijnsdorp, "When does fishing lead to more fish? Community consequences of bottom trawl fisheries in demersal food webs"*Proceedings of the Royal Society B: Biological Sciences*. 280.1769 (2013).

[103] See [92] above.

[104] Biniam Samuel-Fitwi et al., "Aspiring for environmentally conscious aquafeed: Comparative LCA of aquafeed manufacturing using different protein sources"*Journal of Cleaner Production*. 52 (2013): 225–233; Jones JG, "POLLUTION FROM FISH FARMS"*JOURNAL OF THE INSTITUTION OF WATER AND ENVIRONMENTAL MANAGEMENT*. 4.1 (1990): 14–18; Abdolsamad K. Amirkolaie, "Reduction in the environmental impact of waste discharged by fish farms through feed and feeding"*Reviews in Aquaculture*. 3.1 (2011): 19–26.

[105] ANNE SHERIDAN, *Annual Report on Migration and Asylum Statistics 2007* (The Economic and Social Research Institute Whitaker, 2018); Felicity Lawrence et al., "Revealed: trafficked migrant workers abused in Irish fishing industry | Global development | The Guardian"*Guardian*. (London, 2 Nov. 2015).

[106] See [87] above.

[107] The Dutch Soya Coalition, *Soya Barometer*, 2014.

majority ~75%[108] being used for animal feed production. It is therefore necessary to consider many of the harms associated with soya production as being intrinsically connected to and resulting from production of animal products.
In a recent meta-analysis of 4 LCAs of soy bean a median GHG intensity of 0.58 $kgCO_2e/kg$ was estimated with low levels of deviation between studies[109]. The same study, using 51 LCA values estimated GHG intensity of 0.66 $kgCO_2e/kg$ for pulses and legumes. Normalising median values for soy beans based on a protein content of 0.365 kg(protein)[110]/kg gives an estimated value of 1.59 $kgCO_2e$/kg(protein). Normalising median pulse and legume GHG intensity based on a protein content of 0.228 kg(protein)[111]/kg gives an estimated value of 2.89 $kgCO_2e$/kg(protein).

4.6.2 Ecosystem Use

As described above soy bean production is associated with deforestation in regions of high biodiversity. However, it is possible to suggest the growth of soy production is directly related to meat consumption and so the substitution of soy for meat results in a net reduction of ecosystem loss. In terms of land use for agricultural production pulse and soy have a land use requirement ~5-10% of intensive beef production[112].

4.6.3 Pollution

In an LCA of different crops, soy and bean production were estimated as having pesticide use, acidification and eutrophication effects of ~2-3 times that of feed crops such as wheat and barley[113], however when normalizing for protein content[114] these differences largely disappeared.

4.6.4 Social Impact

Pulse farming consists a wide variety of practices and scale situated in a wide variety of social contexts in Ireland, the EU and beyond. It is therefore not possible to make definitive statements about the specific impact of pulses, however, as with all farming systems there exists a mix of owner occupied and highly centralised systems that produce various levels of inequality through their production. In the case of soy, as has been described above, there are mixed reports of the social impact of increased soy production for different communities and community members. However, as above in the case of soy as a replacement for meat protein a net reduction in soy production is required.

4.6.5 Cost

A price of 1.40 €/kg for dried soya beans and a range of 1.00 - 3.00 €/kg for a range of pulses dried and canned is estimated.

4.7 Comparative analysis

4.7.1 Climate Change

<u>Item</u>	<u>GHG Intensity</u> $kgCO_2e$/kg(protein)
Low-intensity beef	193.48

[108] Viera Ukropcova and Sarah Halevy, *Appetite for destruction*, 2017.
[109] See [41] above.
[110] See [70] above.
[111] See [70] above average value of 0.228 taken as mean of bean and pea values.
[112] See [91] above.
[113] See [75] above.
[114] See [70] above.

Intensive beef	~less than 193.48
EU chicken	21.9
Irish dairy	39.38
Fish	21.26
Soya	1.59
Pulse	2.89

4.7.2 Ecosystem Use

Item	Ecosystem Impact
Low-intensity beef	High
Intensive beef	High
EU chicken	Med-High
Irish dairy	High
Fish	High
Soya	Low
Pulse	Low

4.7.3 Pollution

Item	Pollution Impact
Low-intensity beef	Med-High
Intensive beef	Med-High
EU chicken	Med
Irish dairy	Med-High
Fish	Med-Low
Soya	Low
Pulse	Low

4.7.4 Social Impact

Item	Social Impact
Low-intensity beef	Low
Intensive beef	Med-Low
EU chicken	Med-Low
Irish dairy	Low
Fish	Med-Low
Soya	Low (as replacement)
Pulse	Low

4.7.5 Price

Item	Price €/kg	Price €/kg(protein)
Low-intensity beef	>8.50	41.06
Intensive beef	>6.00	28.99
EU chicken	>7.4	35.92
Irish dairy	>0.85 (milk)	26.56
Fish	> tbc	tbc
Soya	1.40 (beans dry)	3.84
Pulse	1.00-3.00	4.39-13.16

4.8 Summary

There are significant differences between protein choices in terms of each of the main environmental headings. In particular ruminant animal production has the greatest negative impact in all categories, followed by other animal food production. In all areas plant-based foods have lower negative impact.

5 Comparative Analysis – Tomato

Tomato is one of the most universally used plant ingredients across Irish food businesses. In order to understand the impact of various tomato choices available to Irish food businesses this report will examine the impact of the following products; wholesale imported conventional tomatoes, wholesale Irish conventional[115] tomatoes and small scale organic polytunnel tomatoes.

5.1 Imported conventional tomatoes

The wholesale fresh fruit and vegetable market in Ireland is composed of a range of importer/distributers and secondary wholesalers. In the case of tomatoes imports are sourced from a variety of locations primarily determined by price, which in itself is reflective of season. The secondary wholesaler or food business generally have no input in the choice of import location. Broadly speaking tomatoes imported to Ireland are produced in The Netherlands for the majority of the summer season, for the whole year in Spain and Moroccan tomatoes are imported to the EU in the winter months only due to EU tariffs[116]. Recent developments in LED lighting technology, however, have made year-round growing in The Netherlands more economical. As the growth cycle of tomatoes is less than 1 year, the impact of tomatoes is sensitive to seasonal variation as well as geographic variation. The methods of production vary between these three countries and within these countries as technological change happens at uneven pace between differing growers. In all cases tomato growth can be assumed to be high intensity greenhouse grown tomatoes. In The Netherlands tomato production is characterised by increasingly high tech, hydroponic production in heated greenhouses with the inclusion of technologies such as CO_2 reuse enrichment, water and nutrient recirculation and full climate and ventilation control. In Spain production is in hydroponic production in unheated greenhouses with lower inclusion CO_2 enrichment from external sources, water and nutrient recirculation and generally little full climate and ventilation control[117]. In Morocco production is generally in unheated greenhouses and is soil based[118].

5.1.1 Climate Change

In a meta-analysis of heated greenhouse production of tomatoes based on 33 research values a median GHG intensity of 2.69 $kgCO_2e/kg$. In the same research a GHG intensity of 0.67 $kgCO_2e/kg$ was estimated for unheated greenhouse production[119]. In a survey of three Moroccan farms using unheated soil-based greenhouse production a value of 0.22 $kgCO_2e/kg$ was estimated at farm gate and a value of 0.55 $kgCO_2e/kg$ was estimated when accounting to delivery to market in France[120]. In a study of Spanish high intensity unheated greenhouse production, a value of 0.25 $kgCO_2e/kg$ was estimated at farm gate[121] and a

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[115] "Conventional" denotes non-organic production.
[116] See [24] above.
[117] D. L. Valera et al., "The greenhouses of Almería, Spain: Technological analysis and profitability"*Acta Horticulturae*. 1170 (2017): 219–226; Torrellas et al., "LCA of a tomato crop in a multi-Tunnel greenhouse in Almeria."
[118] See [24] above.
[119] See [41] above.
[120] See [24] above.
[121] See [23] above.

value of 0.33 estimated to regional distribution centre[122]. In a UK LCA of Spanish production, a value of 0.63 $kgCO_2e/kg$ was estimated including transportation to point of sale[123]. In an LCA of tomatoes from the Netherlands to farm gate a value of 0.78 $kgCO_2e/kg$ was estimated[124]. A separate study of tomatoes from the Netherlands estimate a GHG intensity of ~0.85 $kgCO_2e/kg$[125]. A further study of Dutch tomatoes estimates a value of 1.59 $kgCO_2e/kg$[126], however when accounting for upstream emissions the estimated value is 2.4 $kgCO_2e/kg$. Based on the combination of GHG intensities and the range of production sources it is possible to suggest a sensible combined value of GHG intensity is in the range of 1.24 $kgCO_2e/kg$ [127].

5.1.2 Ecosystem Use

As described in each case tomato production is highly intensive greenhouse production. In one study of variations of production method land use for all hydroponic production methods was estimated 0.029 m^2/kg[128], similar figure of 0.021 m^2/kg was obtained for Moroccan production[129]. As the greenhouses exists as fully- to semi- production environments the biodiversity within the space of the greenhouse is effectively zero. In areas of high concentration of greenhouses there is a significant impact on biodiversity, soil ecosystems. In each location water stress is a result of the production intensity and relative water scarcity. Production in the Mediterranean has been associated with salinity and destruction of local clay and water ecosystems[130].

5.1.3 Pollution

The primary causes of pollution in greenhouse production come from fertiliser acidification and eutrophication of the surrounding ecosystem. In the more technologically advanced production cases this is significantly lowered due to lower fertiliser and pesticide use and through water runoff reuse. The other primary pollution produced by all methods here is plastic pollution from input and output packaging.

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[122] David Pérez Neira et al., "Energy use and carbon footprint of the tomato production in heated multi-tunnel greenhouses in Almeria within an exporting agri-food system context"*Science of the Total Environment*. 628–629 (2018): 1627–1636.

[123] AEA Technology, *The Validity of Food Miles as an Indicator of Sustainable Development*, 2005.

[124] A. Antón et al., "Environmental impact assessment of dutch tomato crop production in a venlo glasshouse"*Acta Horticulturae*. 927.2001 (2012): 781–792.

[125] Jonatan Hogberg, "Comparing global warming potential, energy use and water consumption from growing tomatoes in Sweden, the Netherlands and the Canary Islands using life cycle assesment"Chalmers University of Technology, 2010.

[126] J. C. Pluimers et al., "Quantifying the environmental impact of production in agriculture and horticulture in The Netherlands: Which emissions do we need to consider?"*Agricultural Systems*. 66.3 (2000): 167–189.

[127] Based on a the most conservative value for Dutch tomatoes of 2.4, a median value 0.59 for Mediterranean tomatoes, to give a combined value of 1.24 assuming a mix of 50% Dutch and 50% Mediterranean tomatoes.

[128] See [75] above.

[129] See [24] above.

[130] J. F. Mota et al., "Agricultural development vs biodiversity conservation: The Mediterranean semiarid vegetation in El Ejido (Almería, southeastern Spain)"*Biodiversity and Conservation*. 5.12 (1996): 1597–1617; Centre for Genetic Resources the Netherlands (CGN), *Country Reports the State of The Netherlands Biodiversity for Food and Agriculture*. (UNited Nations Food and Agriculture Organisation, 2015); Arjen Y. Hoekstra and Ashok K. Chapagain, "The water footprints of Morocco and the Netherlands: Global water use as a result of domestic consumption of agricultural commodities"*Ecological Economics*. 64.1 (2007): 143–151.

5.1.4 Social Impact

Highly intensified greenhouse agriculture is extremely centralised and as such is associated with unequal distribution of earnings from production. In the Netherlands there is some isolated reporting of negative labour practices and conditions[131], meanwhile in Spain there is significant reporting of slavery, forced labour, trafficking and other negative labour practices associated with greenhouse production[132]. In Morocco, there are high levels of trafficking and slavery reported generally[133] and the tomato industry has been identified for negative labour practices[134]. In all cases lowest paid workers are paid less than a living wage in their economy.

5.1.5 Cost

There are seasonal variations in cost of imported tomatoes with average ranges varying from €6.00 to €13 for a 5kg box.

5.2 Irish conventional tomatoes

Irish conventional tomatoes are grown primarily in greenhouses in and around North Dublin. Similar to the Netherlands production is highly technical with the inclusion of technologies such as CO_2 reuse enrichment, water and nutrient recirculation and full climate and ventilation control powered by electricity and natural gas.

5.2.1 Climate Change

In a meta-analysis of heated greenhouse production of tomatoes based on 33 research values a median GHG intensity of 2.69 $kgCO_2e/kg$. However as detailed above studies of Dutch tomatoes estimated values of 0.78 $kgCO_2e/kg$, ~0.85 $kgCO_2e/kg$, 2.4 $kgCO_2e/kg$. In a UK governmental commissioned LCA of UK heated greenhouse tomato production a value of 2.39 was estimated including transportation[135]. A further survey of UK tomato production including transportation estimated a GHG intensity of 2.24 $kgCO_2e/kg$[136]. It is therefore reasonable to estimate based on the three studies that include transport emission a mean value of 2.27 $kgCO_2e/kg$.

5.2.2 Ecosystem Use

As described above sealed greenhouse agriculture has a local impact on biodiversity and water use. However, as greenhouse production in Ireland is relatively less concentrated than in the case of the Netherlands, Spain or Morocco this effectively lower concentration can be said to lower the ecosystems use impact.

5.2.3 Pollution

As with imported conventional tomatoes the sources of pollution come from fertilizer use, pesticides and packaging materials. As Irish greenhouse production is generally high-technology the use of pesticides and fertiliser is lower than in Spanish and Moroccan production.

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[131] Ertan Basekin and BArt Mos, "Roofbouw in de kassen"*De Telegraaf*. , 4 Nov. 2017.
[132] Thomas Chesney et al., "Understanding labour exploitation in the Spanish agricultural sector using an agent based approach"*Journal of Cleaner Production*. 214 (2019): 696–704.
[133] The Global Slavery Index, *The Global Slavery Index 2016* (The Global Slavery Index, 2016).
[134] Fair Food International, *The fruits of their labour The low wages behind Moroccan tomatoes sold in European supermarkets*, 2014.
[135] See [123] above.
[136] J. Webb et al., "Do foods imported into the UK have a greater environmental impact than the same foods produced within the UK?"*International Journal of Life Cycle Assessment*. 18.7 (2013): 1325–1343.

5.2.4 Social Impact

Highly intensified greenhouse agriculture is extremely centralised and as such is associated with unequal distribution of earnings from production. Whilst there are no reports of specific labour practice violations or forced labour in Ireland it is expected that lower paid workers are paid less than a living wage.

5.2.5 Cost

The prices of Irish grown tomatoes is generally about €12.00 for a 6kg box.

5.3 Irish organic tomatoes

Irish organic tomatoes are grown in smaller quantities than conventional greenhouse tomatoes. Production is seasonal and tomatoes are available in the summer months. Production is soil based, in plastic poly-tunnels and features crop rotation.

5.3.1 Climate Change

There are no available studies of Irish organic tomato production. As detailed above unheated greenhouse production of tomato is estimated at 0.67 $kgCO_2e/kg$ based on 8 research values. Traditionally, organic production methods achieve a lower crop yield per area than conventional production methods, however practices of crop diversification such as present in Irish production can help to lower this[137]. In a comparison of organic and conventional production of tomatoes in Austria a reduction to roughly 14% of total GHG intensity was estimated for organic production[138]. A further study estimated a GHG intensity of 22% of that of conventional production methods[139].

5.3.2 Ecosystem Use

A study of the comparative impact of biodiversity on organic versus conventional farms indicates a lower impact on local biodiversity across varied species for most farm types[140], this more than offsets the biodiversity impact of increased land use required compared to conventional production.

5.3.3 Pollution

In a review of LCAs of organic versus conventional tomato production there were significant reductions in the negative effects of acidification (86%), eutrophication (17%) and pesticide use.

5.3.4 Social Impact

Lower intensity organic greenhouse agriculture in Ireland is generally characterised by small family owned farms. As such there are reduced levels of centralisation and larger portions of the income generated got to the producers. However, whilst wages may exceed those of larger conventional farms it is expected that lower paid workers are paid less than a living wage.

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[137] Saul A. Cunningham et al., "To close the yield-gap while saving biodiversity will require multiple locally relevant strategies"*Agriculture, Ecosystems and Environment*. 173 (2013): 20–27; Ponisio et al., "Diversification practices reduce organic to conventional yield gap."

[138] Michaela Clarissa Theurl et al., "Contrasted greenhouse gas emissions from local versus long-range tomato production"*Agronomy for Sustainable Development*. 34.3 (2014): 593–602.

[139] Matthias S. Meier et al., "Environmental impacts of organic and conventional agricultural products - Are the differences captured by life cycle assessment?"*Journal of Environmental Management*. 149 (2015): 193–208.

[140] See [12] above.

5.3.5 Cost

An average price of 4.5 €/kg is estimated throughout the season.

5.4 Comparative analysis

5.4.1 Climate Change

Item	GHG Intensity $kgCO_2e/kg$
Imported conventional	1.24
Irish conventional	2.27
Irish organic	<0.67

5.4.2 Ecosystem Use

Item	Ecosystem Impact
Imported conventional	Med-High (Local)
Irish conventional	Med-High (Local)
Irish organic	Low

5.4.3 Pollution

Item	Pollution Impact
Imported conventional	Med-High
Irish conventional	Med-Low
Irish organic	Low

5.4.4 Social Impact

Item	Social Impact
Imported conventional	Med-High
Irish conventional	Med-Low
Irish organic	Low

5.4.5 Cost

Item	Cost €/kg
Imported conventional	1.20-2.60 (Seasonal variation)
Irish conventional	2.0
Irish organic	4.5

5.5 Summary

In terms of climate change the most significant factor in tomato production is seasonal variation and climate suitability, with unheated production having a significantly lower negative impact. In terms of other environmental impact categories Irish organic production has a significantly lower environmental impact. There is enough evidence to suggest that in some countries there are significant negative social impacts that go beyond legally acceptable levels of wage inequality.

7 Comparative Analysis – Packaging

In recent years takeaway packaging has come to form a significant part of the waste stream of some cafes and restaurants. Due to the competing requirements of containing liquids, cost and lightweight construction these have traditionally been manufactured from plastic or composite (paper/plastic) constructions. Whilst plastic recycling is available in Ireland for some plastics within the green waste stream, composite recycling is not. There is, however, a general misconception about the recyclability of composites and these are disposed of in high proportion in the green waste stream[141]. In recent years more biodegradable or compostable alternatives have come to the market most commonly composed of polylactic acid (PLA) and less commonly of polyhydroxyalkanoates (PHAs) and polybutylene succinate (PBS). These plastics are manufactured from plant material and generally are recyclable and/or biodegradable, however, this is only the case under specific conditions[142,143]. In Ireland plant-based plastics are not recycled under green waste streams, commercial brown waste streams have facilities for industrial composting and black waste streams are currently incinerated and landfilled.

In order to understand the impact of various packing choices available to Irish food businesses this report will examine the impact of the following choices; composite and plastic takeaway containers (petroleum plastic), commercially compostable takeaway containers (bioplastic) and reusable containers. Due to the range, of different packaging applications, formats, and products it is difficult to obtain a common unit of analysis (such as 1kg of protein or 1kg of tomato as above), therefore it is useful to invert the schema used thus far in this report and to compare each item simultaneously under each of the five analysis areas.

7.1 Climate change

In an LCA of comparing PLA and PP and when accounting for emissions from end of life disposal GHG intensity for PLA and PP was 0.74 $kgCO_2e/kg$ and 0.75 $kgCO_2e/kg$ respectively. However, when accounting for the lighter density of PLA and thus the need for higher usage in semi-rigid containers the PLA packaging had a GHG intensity of 12% higher than PP[144]. In a survey of LCAs of disposable cup packaging PLA and PP coated paper cups were considered to have broadly equal GHG intensity whilst plastic and wax coated paper were considered to have higher GHG intensities[145]. A further study indicated GHG intensity reductions for PLA and bio-PET over new petrochemical-PET however recycled PET had similar GHG intensities[146]. In an assessment of bioplastic and plastic products including differing end of life disposal options PLA and PP scored roughly equivalent average GHG intensities across landfilling and incineration disposal options,

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141 See [27] above.

142 Kunnika Changwichan, Thapat Silalertruksa, and Shabbir H. Gheewala, "Eco-efficiency assessment of bioplastics production systems and end-of-life options"*Sustainability (Switzerland)*. 10.4 (2018): 1–15.

143 Jeffrey J. Kolstad et al., "Assessment of anaerobic degradation of Ingeo™ polylactides under accelerated landfill conditions"*Polymer Degradation and Stability*. 97.7 (2012): 1131–1141.

144 Gregory M. Bohlmann, "Biodegradable packaging life-cycle assessment"*Environmental Progress*. 23.4 (2004): 342–346.

145 Eugenie Van der Harst and José Potting, "A critical comparison of ten disposable cup LCAs"*Environmental Impact Assessment Review*. 43 (2013): 86–96.

146 Li Shen, Ernst Worrell, and Martin K Patel, "Comparing life cycle energy and GHG emissions of bio- based PET, recycled PET, PLA, and man-made cellulosics"*Biofuels, Bioproducts and Biorefining*. 6 (2012): 625–639.

however, in each case identified PBS bioplastics had far lower GHG intensities[147]. It is thus possible to suggest that bioplastics can be considered as roughly equivalent or marginally lower than conventional plastics in terms of GHG emission intensity.

In a survey of comparative analysis of the reuse of ceramic containers compared with disposable paper cups found a median reuse requirement of 56 times to offset the increased production energy use[148]. In one of the studies, in which the ceramic reuse requirement was estimated at 39 times, reusable plastic was estimated at as having a reuse requirement of 17 times[149]. In each case there was a high level of sensitivity to the efficiency of washing. It is therefore possible to suggest that reusable materials can have a lower GHG intensity based on the level of reuse. In a study of drinking straws paper straw had a lower GHG intensity than plastic straws[150].

7.2 Ecosystem use

Comparing conventional plastic and compostable packaging options we can assume that paper use in both is equivalent. Paper is manufactured from wood generally grown in sustainably managed forests or from recycling. Conventional plastics are manufactured from oil and thus have low ecosystem use. Bioplastics are manufactured from plant-based feedstocks and therefore have land-use and water impacts at the point of production; given the range of sources of this material and the potential for production from waste materials such as bagasse it is difficult to quantify the impact with accuracy. Ceramic, glass and reusable plastic containers are assumed to have low ecosystem use.

7.3 Pollution

Pollution from packaging is sensitive to its disposal. In Ireland correctly disposed of packaging can be considered to be incinerated or landfilled (both bioplastic and composite) with all to be incinerated on completion of the Ringaskiddy incinerator project. Incorrectly disposed of packaging in the green waste stream can cause fouling of recyclable material. The impact of this is considered similar for both conventional and bioplastic products. In the case of incineration bioplastics and some plastics such as PP commonly used in packaging are safely combustible to inert combustion products. However certain plastics such as PVC produce harmful combustion products such as hydrochloric acid and dioxins[151]. The production of bioplastics requires the use agricultural methods that include the use of pesticides and which produce effects such as eutrophication and acidification. In a study of the relative impact of PC, PP and PLA drinking cups PLA scored marginally higher for the production of negative carcinogens and ecotoxicity than both PP and PC[152]. Similarly, in a study of PP, PLA, PHA and PBS the plant-based plastics all scored higher than

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[147] See [142] above.

[148] Bill Sheehan, *Greenhouse Gas Impacts of Disposable vs Reusable Foodservice Products: Literature Review and Inventory*, 2017.

[149] Martin B. Hocking, "Reusable and disposable cups: An energy-based evaluation"*Environmental Management*. 18.6 (1994): 889–899.

[150] Megan Tolbert and Katie Koscielak, *HSU straw analysisAppropedia*. , 2018.

[151] Brian Momani, "Assessment of the impacts of bioplastics: Energy usage, fossil fuel usage, pollution, health effects, effects on the food supply, and economic effects compared to petroleum based plastics"*Worcester Polytechnic Institute*. March (2009): 1–58.

[152] An Vercalsteren, Carolin Spirinckx, and Theo Geerken, "Life cycle assessment and eco-efficiency analysis of drinking cups used at public events"*International Journal of Life Cycle Assessment*. 15.2 (2010): 221–230.

petrochemical PP under a modelled scenario of 100% incineration and PP, PLA and PHA scored similar in a mixed landfill and composting/recycling scenario[153].

In the cases of improper disposal, plastic pollution has significant negative effects on ecosystems through the ingestion of microplastics[154]. Currently there is insufficient evidence to determine the impact of plant-based plastics on ecosystems, however, some studies have indicated that there may be lower levels of harm to certain species[155].

7.4 Social Impact

There is no significant difference that can be indicated between petroleum or plant-based plastic products, similarly it is difficult to quantify any differences between the reuse of containers and the use of disposable containers except in the case of improper disposal which creates litter.

7.5 Cost

Biodegradable packaging generally has a higher cost than traditional petrochemical plastic packaging. Whilst this varies from product to product biodegradable packaging generally ranges from 20% for larger containers to >300% more expensive for smaller items like cutlery[156]. Similar to energy use reuse of containers financial cost is dependent on number of reuses. Initial cost of containers varies from 10 to 100 times greater dependent on container type and reuse requirement is reflective of this variance.

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[153] See [142] above.

[154] For example see [7] above or S. C. Gall and R. C. Thompson, "The impact of debris on marine life"*Marine Pollution Bulletin*. 92.1–2 (2015): 170–179; Bas Boots, Connor William Russell, and Dannielle Senga Green, "Effects of Microplastics in Soil Ecosystems: Above and Below Ground."*Environmental Science & Technology*. 53.19 (2019): 11496–11506.

[155] Sandrine Straub, Philipp E. Hirsch, and Patricia Burkhardt-Holm, "Biodegradable and petroleum-based microplastics do not differ in their ingestion and excretion but in their biological effects in a freshwater invertebrate Gammarus fossarum"*International Journal of Environmental Research and Public Health*. 14.7 (2017).

[156] Nisbetts, "Nisbetts.ie," n.d., online, Internet, 15 Oct. 2019. , Available: https://www.nisbets.ie.

7.7 Comparative analysis

7.7.1 Climate Change

Item	GHG Intensity relative $kgCO_2e$
Petroleum plastic	medium
Bio plastic	medium
Reusable containers	low after reuse point

7.7.2 Ecosystem Use

Item	Ecosystem Impact
Petroleum plastic	low
Bio plastic	med-low
Reusable containers	low

7.7.3 Pollution

Item	Pollution Impact
Petroleum plastic	med
Bio plastic	med
Reusable containers	low

7.7.4 Social Impact

Item	Social Impact
Petroleum plastic	n/a
Bio plastic	n/a
Reusable containers	n/a

Cost

Item	Cost
Petroleum plastic	med
Bio plastic	med-high
Reusable containers	low

7.8 Summary

Given the current situation of waste processing in Ireland there is insignificant differences in all environmental impact between plant and petrochemical derived plastic products. In all cases reuse of containers represents significantly lower environmental impacts.

8 Discussion

8.1 Limitations

Before discussing the some of the findings contained within the research above it is necessary to highlight the limitations some of the limitations of the research.

As highlighted above the research consists of secondary research and meta-analysis of existing research, as such, the availability and reliability of source data is a significant limiting factor. In this regard, the limited availability of data with which to describe accurately the specific supply chains of particular products in the Irish context is a factor. Similarly, the rate of change of production practices in some fields, for example tomato production, exceeds the speed of academic research and as such some of the most current production techniques may not be captured in the research. Similarly given the competitive nature of academic research funding alternative production methods may be less well researched than more common methods. Finally, research methodologies used in LCAs and in other research vary widely and there is little agreement on the range of inputs, outputs and boundaries of any given production system[157].

Beyond the limitations in data availability and accuracy any research that attempts to capture and represent a system of high complexity in a way that is not complex must by its nature eliminate some of that complexity. As such there exist examples of production methods, systems, techniques that will act as outliers to the analysis contained above. Notwithstanding these limitations, this report aims to present a picture that is representative of the situation as it occurs to Irish food businesses given the available independent data. Whilst individual values should be taken as containing an element of uncertainty the overarching trends can be considered as having a high degree of certainty.

8.2 Significance of food findings

As the research shows there are significant differences in the negative impact of dietary choices on various environmental systems. For example, a daily 150g serving of beef contains 31g of protein and produces 6kg of CO_2, whereas a protein equivalent serving of 136g of legumes produces 0.09kg of CO_2, a saving of 5.91kg. In the case of all other emissions contained within a meal being equal a change from beef to legumes in a daily meal for one year (365 meals) would produce and equivalent saving of 2,157 $kgCO_2e$, i.e. a total emission of 33kg for legume-based dishes instead of 2,190 $kgCO_2e$ for beef-based dishes. Recalling current Irish emissions of 12,650 $kgCO_2e$ and a target individual total emission rate of 3,120 $kgCO_2e$ to meet GHG emission targets by 2030 it is clear that reducing meat, and in particular high emissions intensity meats such as beef and lamb has the potential to play a significant role in achieving emission targets.

Taking one of the other examined items, for example tomatoes, and making a similar substitution from the highest GHG intensity option (Irish conventional production) to the lowest GHG intensity (Irish organic production) and assuming a portion of 150g the carbon emissions are 0.34 $kgCO_2e$ and 0.10 $kgCO_2e$ respectively. Assuming a similar substitution over a year a change from 124 $kgCO_2e$ to 36.5 $kgCO_2e$ yields a saving of 87.5 $kgCO_2e$. Whilst this saving is significant (0.7%) of current Irish emissions it is clear that savings in different areas produce vastly impacts on total emissions.

[157] Mary Ann Curran, "Strengths and Limitations of Life Cycle Assessment."in *Background & Future Prospects in Life Cycle Assessment*. (Dordrecht: Springer, 2014), 189–206.

8.3 Agricultural solutions

Whilst changes in diet present significant opportunities for reducing negative climate change, ecosystems use and pollution impacts there is also potential for changes in the practices through which food is produced that can also contribute to reducing these negative impacts.

With respect to reducing biodiversity impacts and reducing GHG intensity of meat through alterations in the nitrogen cycle of soils agroecological systems which include highly diverse growing practices sensitive to local conditions appear to offer some potential benefits [158]. At the same time seasonally appropriate production of crops through intense methods (e.g. greenhouse production) also offer potential for high rates of production with minimal land-use and energy impacts. Additionally, experimental techniques are being used to try and reduce the methane emissions of animals through altered feed stocks, however at present the results of these offer fractional savings[159].

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[158] See [7], [51] and [60].

[159] Such as reported in H. Guan et al., *Efficacy of Ionopeores in Cattle Diets for Niitigation ofJournal of Animal Science*. , vol. 84(7), 2006; S.L Woodward et al., "Early indications that feeding lotus will reduce methane emissions from ruminants"*Proceeedings of the New Zealand Society of Animal Production*. 61 (n.d.): 23–36; R. D. Kinley and A. H. Fredeen, "In vitro evaluation of feeding North Atlantic stormtoss seaweeds on ruminal digestion"*Journal of Applied Phycology*. 27.6 (2015): 2387–2393.

Research Details
Research carried out by Tom O'Dea, commissioned by The Fumbally, and supported by twenty-eight Irish Food Businesses:

3FE / Airfield House / Ard Bia / Bujo / Bunsen / Camerino / Camille Thai Take Away / Cully & Sully / Donworth Capital / Dublin Food Co-op / Gaillot & Grey / Hotel Doolin / ITSA Group / Little Bird / Loam / Meet Me in the Morning / Network Café / Nobo / Organico / Proper Order / Scéal Bakery / Tang / The Cheese Press / The Farmhouse Café / The Happy Pear / The Hopsack / White Mausu //