The impact of climate change on dairy production

be safe be healthy be well

The potential food safety, economic and environmental impacts of climate change on the dairy production chain on the island of Ireland

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Foreword and acknowledgments

This is a technical report of a research project funded by ***safe*food** to investigate the potential food safety, economic and environmental impacts of climate change on the dairy production chain on the island of Ireland. The key objectives of the research were

1. Identify and rank the main vulnerabilities to climate change in the dairy food chain
2. Identify and evaluate possible mitigation strategies – ways to reduce or offset the effects of climate change.

To achieve this an extensive review of available research literature was undertaken. The project also included a series of semi-structured interviews – pre-determined questions that led to further discussion – with a range of experts associated with the dairy sector.

***safe*food** wishes to thank the Principal Researcher on this project, Prof Thia Hennessy, Professor and Chair of Agri-Food Economics and Head of the Department of Food Business and Development at Cork University Business School, University College Cork. Thanks are also due to Prof Hennessy's research colleagues in Teagasc, Dr Trevor Donnellan, Dr Maeve Henchion, Dr Mary Brennan and Dr Paula Cullen, and to Dr Katrina Campbell, lecturer at the Institute for Global Food Security at Queen's University Belfast, who collaborated on this project.

Executive summary

The economic importance of the dairy sector at both farm and processing level on the island of Ireland (IOI) is well established. It is by some distance the most profitable of the mainstream farm systems on the IOI, with average farm income levels well ahead of those on beef, sheep and tillage or crop-growing farms.

Growth prospects for the dairy sector are considered to be very positive given the strong international demand for dairy products and the recent scrapping of the European Union (EU) milk quota system. Dairy farmers in both the Republic of Ireland (ROI) and Northern Ireland (NI) can produce milk at relatively low cost making them particularly competitive within Europe and even globally. The international competitiveness of the sector, together with the ambitions of the dairy processing industry, suggests that milk and dairy product production on the IOI can grow for the foreseeable future.

It is important to examine the issues that could challenge this ambition. One such issue is that of *climate change*. "Climate change" generally means long-term changes in typical weather patterns for an area, such as changes in air pressure, sea temperatures, average rainfall and the frequency of extreme weather events.

This project set out to establish what is known about the potential impact of climate change on the dairy sector, by

1. Conducting an examination of the available research on the possible impact of climate change on the IOI.
2. Establishing what stakeholders know about climate change and the possible effects that it could have on the dairy sector. This research also established levels of awareness regarding mitigation strategies – ways to reduce or offset the effects of climate change on the sector. It was achieved through a series of 20 semi-structured interviews – a set of questions leading to open discussion – with a range of stakeholders in both the ROI and NI. The stakeholders included policy makers, researchers, dairy farmers and dairy processing industry representatives, suppliers of "agri-inputs" (agricultural inputs, such as animal feed, fertiliser, farm equiptment, and so on), environmental interests and the retail sector. Interviews were conducted during October and November 2016.

It is clear that the dairy sector has good foundations from which to address climate change concerns. Various committees, working groups and peer learning environments are in place at both the processing and farm level. If these were not already in existence, they would have been at the top of the list of recommendations.

Some research on the vulnerability of the food chain to climate change impacts has been conducted an international context. Some studies have looked at the implications for both food safety and economic viability. However, relatively little research has focussed specifically on potential impacts on the dairy chain, and there are no studies focussing solely on the IOI. The current study addresses this knowledge gap. Based on a review of the available literature and the information gathered from the stakeholder interviews, key research findings were developed.

Climate change

- The level of awareness regarding climate change among the various stakeholders in the dairy supply chain is high. There is agreement that collective action is required to address the issue of climate change.
- Climate change presents both threats to and opportunities for the Irish dairy sector.
- The major threats identified by stakeholders were, in order of importance,
    - The impact of extreme weather events
    - Potential implications for the availability and price of animal feeds
    - The implications for fodder production
    - The emergence of new diseases and pests
    - Changing consumer attitudes towards dairy products.
- Interestingly, climate-related policies were not identified as a major threat.
- The opportunities were identified as
    - The IOI's proven position as a world leader in carbon-efficient milk production
    - The strong presence of "Origin Green" in ROI[1]
    - The potential opportunities that might arise due to the development of unfavourable climate conditions in some of the world's key milk producing countries.
- Science and technology can play a major role in mitigating climate change. There was a general view that there are technological solutions available but that there are obstacles to getting the research knowledge from the scientist to the farmer. Furthermore, while there are many engaged farmers participating in discussion groups and other initiatives, a large group of disengaged farmers also persists.
- Climate change related policy, especially policy developed in a global context, is an issue. There was some insistence that global policies should take account of "carbon leakage"2 and that policies or campaigns to reduce dairy consumption are a major threat to the sector.
- Mitigation measures were identified. They fall into two categories:

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[1] Origin Green a programme operated by government, the private sector and food producers through Bord Bia, the Irish Food Board in the ROI to encourage the sustainable production of food.

[2] Carbon leakage refers to the consequences of food production being moved to jurisdictions which have less stringent climate policies thereby resulting in higher global greenhouse gas emissions.

1. Measures to address the impact of climate change on dairy production (although to some extent climate change is seen to have both positive as well as negative implications or consequences in an IOI context
2. Measures to address the impact that dairy production has on climate, such as new types of fertiliser, better animal genetics and more effective circulation of new technologies so that they are adopted by a greater share of farmers.

Food safety

- The increase in the number of publications focussing on climate change and food safety shows a growing concern about the potential impacts in this area.
- A number of food safety risk channels were identified. These include pathogens, chemical contaminants and natural toxins.
- Extreme changes in climate can affect the microbiological safety of food. Conditions favourable to pathogen growth will result in an increased risk of food contamination, including new routes of transmission.
- One of the most widespread food safety hazards within the dairy industry is mycotoxins that emerge in animal feed, mainly in the form of aflatoxins. These compunds are toxic to humans and animals. The future climate on the IOI is projected to be warmer and wetter and therefore favourable to the spread of such toxins during harvesting and storage of crops. If crop yields on the IOI are adversely affected by climate change, this will increase farmers' reliance on imported feed.
- Aflatoxin B1 is one type of mycotoxin that poses a threat to the dairy industry. The toxin can be easily transferred to milk when cattle are fed contaminated feedstuffs. It is metabolised to aflatoxin M1 which can be detected in milk.
- In wetter conditions such as those predicted for the IOI, animal diseases may become more of a problem. Increased use of veterinary medicines and anthropogenic (man-made) chemicals may be necessary. This creates the potential for transmission of chemical residues into the food chain.
- Should animal viruses become endemic on the IoI, added pressure to use antiviral drugs may become more commonplace.
- This increased use of veterinary medicines may lead to drug resistance becoming more problematic to the dairy industry.
- The more frequent and intense rainfall that is predicted could encourage the spread of perchlorate through surface runoff and the waterlogging of fields where livestock graze.This could increase the threat of intake by cattle in particular with the potential to enter the food chain via cow's milk.

- Alkaloids are secondary plant metabolites that are an area of growing concern. The projected temperature increase may elevate the level of these toxins in feed which may cause issues in animal health and food production in the dairy sector.
- The more frequent and intense rainfall that is predicted could result in greater contamination of both silage and grazing pasture by heavy metals. These contaminants may originate from geochemical sources, such as the soil or bedrock, or even anthropogenic sources, such as human pollution. Given that cattle production on the IOI is primarily grass-based, the risks of consuming heavy metals is predictably high. Transmission into milk may become an emerging food safety issue.

Recommendations

A key point is that the ROI and NI are already at an advanced stage in terms of the environmental efficiency of the dairy sector. This sector has a low level of “greenhouse gas” (GHG) emissions per unit of output within Europe and globally. Committees and working groups are in place in the processing sector along with discussion groups at farm level, with the aim of promoting environmental efficiency. A brand new approach to addressing the potential impacts of climate change would place such initiatives high on any list of potential recommendations. Therefore, it should be recognised that there is already a good foundation in place on which to base any further engagement with the dairy sector.

Climate change recommendations

- There is a need to ensure that climate policy is drawn up with full awareness of the potential for carbon leakage.
- Sustainability is an area of concern for a growing number of consumers and the dairy sector needs to develop with sustainability in mind.
- More planning is required to consider how to deal with extreme weather events at both farm and processing level.
- Greater emphasis on the connection between environmental sustainability and profitability at farm level is necessary.
- Technologies being developed to address GHG emissions should involve farmer input at the developmental stage to establish their practicality.
- Farmers that are not engaging with these technological developments must be connected with and brought on board.
- Carbon sequestration on farms by forestry needs greater promotion.
- Research on climate adaptation needs greater prominence.

Food safety recommendations

- More research will be required to identify unknown risks, to protect both animal and human health.
- Greater investment in new technology and monitoring systems will be necessary to prevent the effects of climate change from potentially impacting on food safety at any point on the dairy food chain.
- Extra care must be taken to ensure any pathogens present in raw milk are removed during processing.

- Those within the dairy production and manufacturing areas should be made aware of the potential for climate change to impact on pesticide use.
- Greater exploration of new drugs, or better use of existing drugs, specifically for livestock may be necessary to further reduce the risk of drug residues entering the food chain.
- New screening methods methods and precision sampling for contaminants, including mycotoxins, may be necessary to prevent transmission through the food chain.

Glossary of abbreviations

ARMT	Agricultural Risk Management Team of the World Bank
BSE	Bovine Spongiform Encephalopathy
CAP	Common Agricultural Policy
CH_4	methane
CO_2	carbon dioxide
CPD	Continuing Professional Development
DAERA	Department of Agriculture, Environment and Rural Affairs
DAFM	Department of Agriculture, Food and the Marine
DARD	Department of Agriculture and Rural Development
DON	Deoxynivalenol
EBI	Economic Breeding Index
EDC	endocrine disrupting compounds
EEA	European Environment Agency
ERDSS	Emerging Risk Detection Support System
EU	European Union
GCM	global climate model
GHG	greenhouse gas
HPP	high-pressure processing
ICOS	Irish Co-operative Organisation Society
IDIA	Irish Dairy Industries Association
IOI	island of Ireland
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging technology
MAP	Mycobacterium avium subspecies paratuberculosis
N_2O	nitrous oxide
NDC	National Dairy Council
NI	Northern Ireland
NMA	National Milk Agency
NSAID	non-steroidal anti-inflammatory drug
OECD	Organisation for Economic Co-operation and Development
PCB	polychlorinated biphenyl

PLC	public limited company
RapAgRisk	Rapid Agricultural Supply Chain Risk Assessment
RASFF	Rapid Alert System for Food and Feed
ROI	Republic of Ireland
RPC	Representative Concentration Pathway
SCM	supply chain management
SFI	Science Foundation Ireland
SMP	skim milk powder
TTIP	Transatlantic Trade and Investment Partnership
UK	United Kingdom of Great Britain and Northern Ireland
UNEP	United Nations Environment Programme
US	United States
US EPA	United States Environmental Protection Agency
WMP	whole milk product
WTO	World Trade Organisation

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1 Introduction

1.1 Significance of the dairy sector on the island of Ireland

The dairy sector is an important contributor to the economic activity on the IOI. The export value of dairy products from the ROI exceeded 3 billion in 2014 (Bord Bia, 2015) and totalled £390 million for NI. The ending of the EU milk quota system in April 2015 presents new opportunities for growth in the sector. These opportunities have been identified as key potential contributors to growth in the wider economy in the ROI *Food Wise 2025* report (Department of Agriculture, Food and the Marine [DAFM], 2015b), and in NI in the *Going for Growth* report (Agri-Food Strategy Board, 2013).

The dairy sector in the ROI has increased its milk production by 13% in 2015 and by an estimated further 5% in 2016. In NI, milk production increased by 2.7% in 2015. The increase in milk production in NI has not been as significant as in the ROI. This is because milk quota rights were bought by farmers in NI from farmers in Great Britain for many years in the lead up to milk quota removal. Hence milk production has followed a more gradual upward trend in Northern Ireland.

The cross-border trade in milk has also increased with some 650 million litres of milk exported from NI to the ROI in 2016. This is almost 30% of NI's total milk production, demonstrating the integrated nature of milk production and processing on the IOI.

The relatively low cost of milk production on the IOI has made it an ideal location for milk production in Europe. This low cost base comes from a combination of a favourable climate, which allows grass to form the main portion of the cow's diet, and the skills that dairy farmers have developed to improve farm efficiency. A comprehensive dairy research and extension programme is in place in both the ROI and NI to continue the development of farmers' skills and ensure the efficient production of milk.

1.2 Climate change – a key challenge for the dairy sector on the island of Ireland

While the outlook for the sector is very positive, climate change may represent a fundamental challenge for the continuing development of the dairy sector on the IOI. As outlined by ***safe*food** (2014), regional climate models for the IOI indicate a number of climatic changes that may occur in the coming decades. These changes could give rise to a longer growing season: a predicted 2.5°C increase in July temperatures by 2050, a reduction in summer rainfall levels, an increase in winter precipitation, milder winters and a tendency towards the south east in warming. Climate change will also impact on global dairy production conditions, so raising further indirect threats and opportunities for dairy production on the IOI.

The impact of climate change on the dairy production chain is likely to manifest itself in a number of ways. It has implications for economic viability, food safety and environmental sustainability that are interlinked and cannot be ignored. Flood (2013) has estimated the economic cost of climate change on Irish agriculture to be between 1 billion and 2 billion per year by the mid-21st century. Flood concludes that the most significant climate change impacts relate to pests and diseases, crop yields, flooding, plant and animal stress factors, drought effects and the limited ability to provide sufficient resources for animals during extreme events.

In addition to the possible consequences for production costs, it is important to consider the implications for output prices – the cost of production – at the farm and dairy processor level. It is likely that, as the regions of the world where dairy products can be produced at low cost shrinks, supply will grow at a slower pace than demand. This will result in higher prices for dairy products. Furthermore, the grass-based production system on the IOI is likely to protect it from some of the negative aspects of climate change and so the overall international competitiveness of the sector could improve (Donnellan *et al*., 2011).

1.3 Specific food safety and environmental concerns

*safe***food** (2014) warns that the threat to food safety from mycotoxins may intensify. It is expected, for example, that aflatoxin producing species will become more prevalent with forecasted climate change (Paterson and Lima, 2010), increasing the risks to human health since exposure to this toxin can happen through milk (Prandini et al., 2009). In addition, climate change may lead to more occurrences of animal diseases and increased thermal stress on cattle, affecting dairy production (Stem et al., 1988; Klinedinst et al., 1993).

It is also possible that consumers may become more concerned with the need to tackle climate change and more aware of the negative impacts of livestock production on global warming. This may negatively affect demand for dairy products as consumers move away from animal-based products and especially imported products. See Bailey et al. (2014) for a review of recent thinking in this regard.

As regards the environment, limited availability and increased use of water at farm level are likely to have negative implications. This may present consequences for the usage of fertiliser, and for the management of animal waste and water quality. Changing climate may impact also on herbicide and pesticide requirements, which may have environmental implications. Any adverse impact of climate change on animal productivity, in particular bovine (cow) productivity, will make it more challenging to reduce the carbon footprint of the agri-food sector on the IOI.

1.4 Context of the final report within the broader project

This report represents the first thorough scientific review of the potential safety, environmental and economic impacts of climate change on the dairy industry on the IOI. It provides a clear understanding of a wide range of issues that other sectors of the wider agri-food industry may face in the future. The report includes a series of recommendations for the dairy industry (and for policy makers in the agriculture and environment arenas).

A further output of the study is the creation of the basic elements of an Emerging Risk Detection Support System (ERDSS). It was never intended that the research project would make this system fully operational. However, it has put much of the groundwork in place to permit the development of such a system in the future.

2 Research aims and objectives

2.1 Summary of the project's aims and objectives

The overall objective of this project is to identify key climate change vulnerabilities in the dairy production chain on the IOI and to formulate potential mitigation strategies.

Specifically, the objectives of the project were to

- Conduct an extensive literature review of the potential food safety, economic and environmental impacts of climate change on the dairy production chain on the IOI
- Identify and rank the key climate change vulnerabilities in the dairy food chain
- Identify and evaluate possible mitigation strategies
- Conduct a series of semi-structured interviews with key representatives of various parts of the dairy production chain throughout the IOI to establish their views about the potential vulnerabilities in this chain and possible mitigation strategies
- Provide the basic elements of an Emerging Risk Detection Support System (ERDSS).

2.2 Detailed project aims and objectives

Some research on the vulnerability of the food chain to climate change impacts has been conducted. This includes research by ***safe*food** (2014) examining the implications for food safety, and Flood (2013) who investigated the implications for economic viability. Internationally, relatively little research has been conducted that focussed specifically on the dairy supply chain. No studies were found that focus on this aspect of the agri-food industry in the ROI or in NI. The project set out to address this knowledge gap and to identify climate change vulnerabilities in the dairy production chain on the island of Ireland. A two-tier methodology was used.

1. A review of the international literature was conducted, to compile a list of critical factors or vulnerabilities from inside and outside the supply chain that may be affected by climate change.
2. Experts' judgement was used to
    - Determine the relevance of the identified critical factors in an IOI context
    - Rank the severity of the factors
    - Identify potential mitigation strategies.

The use of expert judgement has been shown to be successful in other studies dealing with uncertainties and scarce or unavailable data in food safety matters (Spiegel et al., 2012).

2.2.1 Literature review

The first stage of the literature review involved mapping the dairy production chain on the IOI. The review separates the production chain into stages:

- Farm input sector
- Farm production sector
- Processing
- Transport
- Consumers at retail level
- Other customers.

The literature review also identified critical factors and potential mitigation strategies. The literature reviewed was diverse and multidisciplinary in nature. It included both academic publications and the "grey literature".[3]

The impact of climate change on food safety issues was investigated and the economic and environmental viability of the dairy production chain was reviewed. The identified critical factors and potential mitigations were grouped according to the listed stages of the production chain. This facilitated interaction with experts at each stage. Although some vulnerabilities are common across the different stages, the likely impacts of climate change may differ and may even be stage-specific.

2.2.2 Expert selection

Experts were drawn from each of the listed stages of the dairy production chain. The experts included various actors from across the supply chain such as farm input suppliers, farmers, processors and retailers; also scientists and academics with a research background and expertise in this area. Experts from organisations that are involved in supplying foreign markets were included to represent the perspective of international customers.

The selection of experts was made to ensure adequate representation from the ROI and from NI. They were selected on the basis of their knowledge and experience. As a quality control measure, the expert list was agreed by all of the project team members in conjunction with *safe*food. The broad membership of the *safe*food "Knowledge Network" in which the project partners and *safe*food interact facilitated a strong positive response from the experts selected to take part.

[3] Grey literature refers to information produced by people and organisations that are not academic or traditional publishers.

2.2.3 Expert engagement

A series of 20 semi-structured, in-depth and face–to–face interviews with the experts was carried out by researchers. Using a semi-structured interview approach allowed scope for a wide-ranging discussion between the interviewee and interviewer. Issues could be explored in some depth during the interview process.

The interview methodology was first conducted on a pilot basis with two of the selected experts. They were asked a range of questions about climate change to discover the factors that they regard as being most important for the dairy sector in an IOI context. In defining importance, the most important considerations for the experts were the likelihood of adverse impacts and the size of the impact. The experts were asked also for their views on potential mitigation strategies to address these adverse impacts.

2.2.4 Emerging Risk Detection Support System (ERDSS)

The results of the literature review, exploration of the dairy chain, identification of climate risks and expert surveys were used to formulate the basic elements that would permit the further development of an Emerging Risk Detection Support System (ERDSS). This is a system for stakeholders from industry and government to identify and control emerging hazards in the dairy production chain. The approach can be likened to a specialised predictor Rapid Alert System for Food and Feed (RASFF). In this system the risks are scored based on impact and the likelihood is scored based on potential occurrence. The scores are then combined.

2.3 Analysis and conclusions

The data collected at the semi-structured interviews was analysed. Using a Likert scale[4], interviewees were asked to rank the threats identified from the literature review in terms of the potential impact on their businesses. These data were then collated and presented, and the threats identified as being most significant were discussed.

Similarly, interviewees were asked to rank potential mitigation strategies in terms of their potential effectiveness, again using a Likert scale. These data were also presented and discussed. In addition, interviewees were asked a series of “open-ended” questions, which require a full answer rather than a simple “yes” or “no”. The responses to these questions were documented and analysed and from this six major themes emerged:

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[4] The Likert scale is used to represent the participants’ attitudes or approaches to the survey topic.

Theme 1: The level of awareness of climate change and the need for collective action is high

Theme 2: Climate change may present an opportunity for the IOI dairy sector

Theme 3: Climate change may present a threat to the supply chain

Theme 4: The challenge of putting research into practice

Theme 5: Policies relating to climate change are a concern for the sector

Theme 6: Forestry as a mitigation strategy

These six themes, along with their rankings, provided the basis for the main findings of the report and the recommendations made.

3 Discussion and key findings

The dairy supply chain is broad. It includes many actors who each contribute goods or services to ensure that dairy products reach the consumer. There are many risks that can interrupt this process. One of the most important potential risks concerns changing climate. Both outputs and inputs (such as animal feed) are reliant on having the appropriate climate to maximise the production of goods for the least cost. Changes in the climate can affect production both negatively and positively. Changes in temperature and rainfall are likely to have an impact on global agriculture, affecting food availability (Porter et al., 2014). Climate change poses a risk to the dairy supply chain as it will affect both average temperatures and precipitation and bring an increased incidence of extreme weather events.

Section 3 of the report is structured as follows.

- An introduction to the issue of climate change.
- Climate modelling and projections (more detail is provided in Appendix 1).
- The potential impact of climate change on agriculture.
- An overview of the dairy supply chain, again in brief, with more detail provided in Appendix 2.
- A risk assessment that outlines the main sources of impact climate change may have on the dairy supply chain on the IOI. More detail is provided in Appendix 3.
- The potential impact of climate change on food safety.
- The selection plan for the expert interviewees and key findings of the interviews are outlined.

3.1 Background on climate change

GHG concentrations in the atmosphere have been increasing significantly over the past century. The levels of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have grown to the highest for at least 800,000 years (Intergovernmental Panel on Climate Change (IPCC), 2014). GHGs are important in regulating the Earth's energy balance. The increase in GHG levels is a key driver of climate change. Their presence in the atmosphere reduces the Earth's ability to radiate the Sun's energy back into space (IPCC, 2014), and so the surface temperature rises.

Different GHGs have different effects on warming and the speed of warming will depend on the relative amounts of each GHG and their properties. Changes due to an increase in GHGs alter the global hydrological cycle as well as atmospheric and oceanic circulation. This in turn affects weather patterns, regional temperatures, precipitation and sea level (IPCC, 2014).

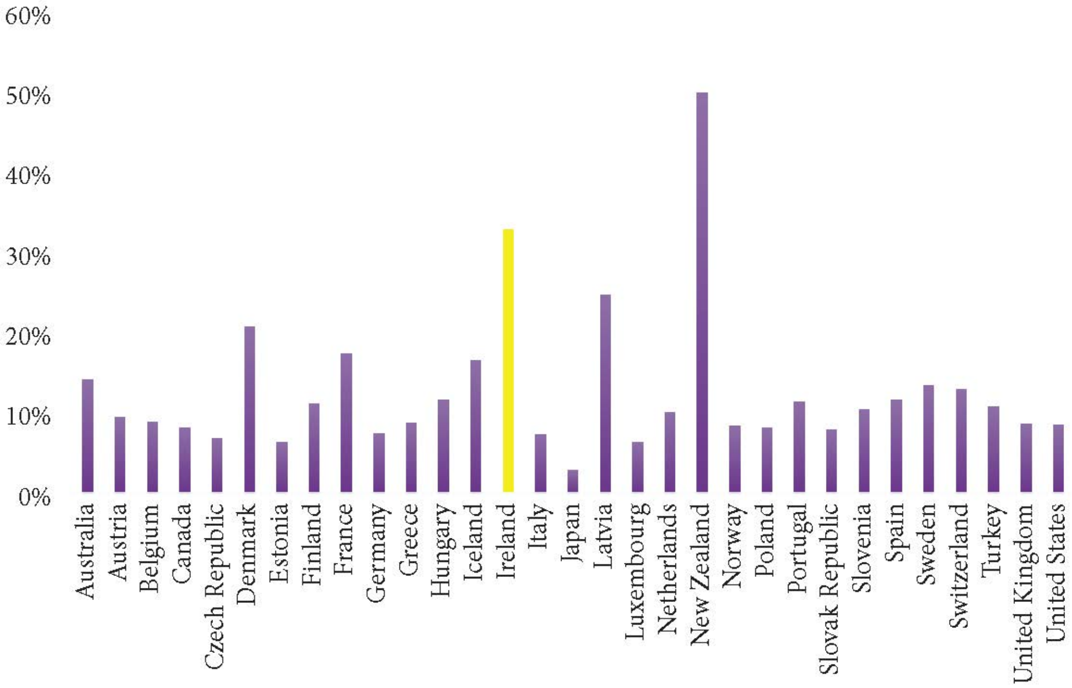
There is a two-way relationship between agriculture and climate change. On one hand, the climate heavily influences production in agriculture. The changing climate may result in alterations to the agricultural sector in terms of the amount produced or possibly land use changes. On the other hand, agriculture also contributes to climate change. It is responsible for 10 to 12% of global GHG emissions (Tubiello et al., 2013). The sector was the largest contributor of non-CO_2 GHG emissions, accounting for 54% in 2005 (United States Environmental Protection Agency [US EPA], 2012).

Agriculture in the ROI contributed 32% of the total GHG emissions in the ROI in 2014 (European Environment Agency [EEA], 2016). Agriculture in NI contributed a similar amount of total GHG emissions at 29% in 2013 (Department of Agriculture, Environment and Rural Affairs [DAERA], 2015). NI contributed a disproportionately high share of total GHG emissions from agricultural sources compared with the United Kingdom (UK) as a whole. The share of agricultural emissions in both the ROI and NI is significantly higher than in other developed economies, with the exception of New Zealand (Figure 3.1).

The dairy sector in the ROI accounts for approximately one third of agricultural GHG emissions and 10% of total emissions (Lesschen et al., 2011). Casey and Holden (2005) used the life cycle assessment methodology to estimate emissions that result from milk production on an average farm in the ROI. They found that up to 1.51 kilograms of CO_2-equivalent emissions occurred per unit of energy-corrected milk[5] produced on an average farm per year. The main sources of these emissions were enteric fermentation (digestive gases) (49%), fertiliser (21%), concentrate feed (13%), manure management (11%) and electricity and diesel consumption (5%).

[5] Energy Corrected Milk determines the amount of energy in the milk based upon milk, fat and protein and adjusted to 3.5% fat and 3.2% protein.

Figure 3.1: **Share of total GHG emissions from agricultural production by OECD country in 2014**

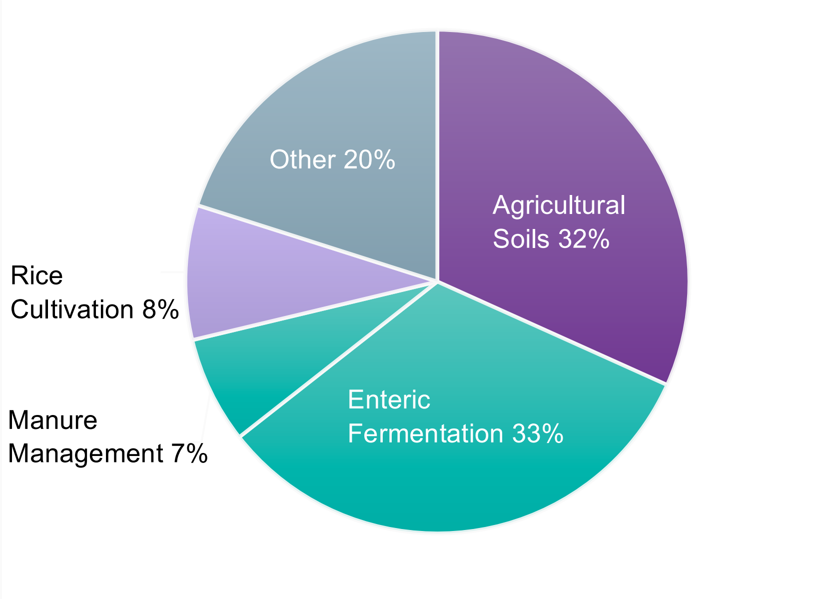


Source: Organisation for Economic Co-operation and Development (OECD), 2016.

The sources of global non-CO_2 agricultural emissions in 2005 are shown in Figure 3.2. The two largest were found to be soils and enteric fermentation. In combination, these made up nearly two-thirds of non-CO_2 emissions.

Agricultural soils release N_2O into the atmosphere. N_2O is produced naturally in soils but additional nitrogen added to the soils in the form of fertilisers and animal manure increases the amount emitted. Enteric fermentation resulting from the normal digestive processes of livestock leads to CH_4 emissions. The quantity, quality and type of feed are significant in determining the amount of CH_4 emissions (US EPA, 2012).

Figure 3.2: **Global agricultural emissions by source in 2005**



Source: US EPA, 2012.

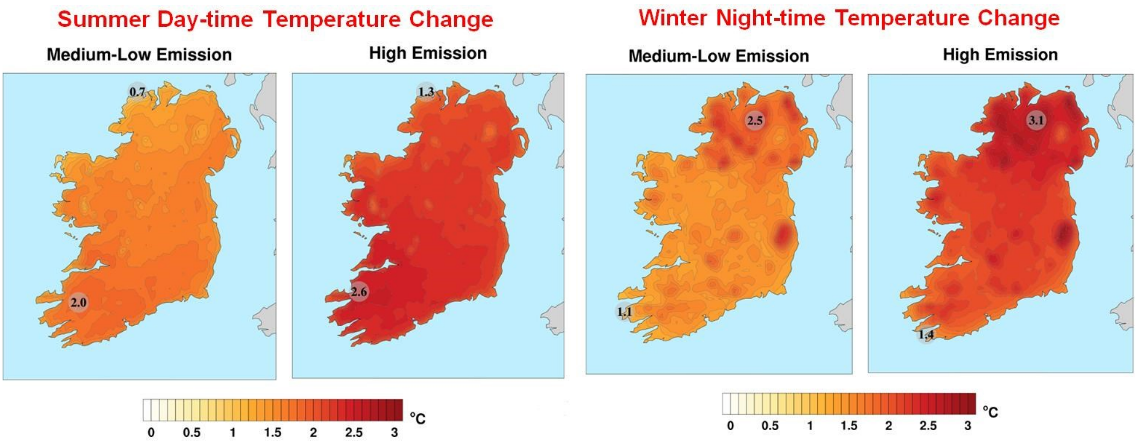
3.2 Climate modelling and projections

Climate models are used to simulate the impact of greenhouse gases on climate change and to project future climatic conditions. Under all emission scenarios that have been modelled, surface temperatures are predicted to rise. The Fifth Annual Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013) estimates that globally temperatures will increase by 0.3 to 4.8°C by the end of the 21st century depending on emission levels. These temperature increases are not expected to be regionally uniform. The changes are projected to be greater at higher latitudes with mean European temperatures projected to exceed the global average. Precipitation levels are projected to rise, with increases of 1 to 3% “likely” under most scenarios.

Nolan (2015) used an enlarged “ensemble” or range of climate models at high resolution to model the impact of climate change on the IOI. The results suggest that by the middle of the 21st century, with low to medium emissions, the mean temperatures over Ireland will have increased by 1 to 1.5°C in the summer and 0.5 to 1.5°C in the winter. Changes in temperature extremes (as opposed to changes in temperature means or averages) are more likely to have an important impact on lives and livelihoods (Easterling and Wehner, 2009).

Nolan (2015) predicts that winter nights will be warmer for Ireland (Figure 3.3). The lowest 5% of night-time temperatures for the low to medium emission scenarios show a greater increase in temperature in the northern part of the IOI of 2.5°C, compared with 1.1°C in the south. The highest 5% of summer daytime temperatures are also expected to increase, with those in the southern part of the IOI increasing more than in the north. In a low to medium emissions scenario, this increase ranges from 0.7°C to 2°C.

Figure 3.3: Projected summer daytime (highest 5%) and winter night-time (lowest 5%) average temperature changes in 2041 to 2060 compared with 1981 to 2000 averages



Source: Nolan, 2015.

Furthermore, Nolan projects the number of ice and frost days to decrease significantly by the middle of the century. Up to 10% less annual precipitation is projected for the future period (2041 to 2060) relative to the period from 1981 to 2000. This reduction is not equal over the seasons, with summer projected to experience greater reductions in precipitation. Heavy rainfall events (days with more than 20mm of rain) are projected to increase by approximately 20% during the autumn and winter months. However, the number of droughts are also projected to rise, with the frequency of dry periods increasing by 7 to 28% by the mid-21st century.

3.3 Climate change and agriculture

The marginal change in mean temperatures is likely to have a mixed effect for agriculture on the IOI. The warmer average temperature is positive for grass growth. However, this may also lead to ecosystem changes giving rise to new pests and diseases that can thrive in warmer temperatures. In the case of extreme weather events, livestock may also suffer from heat stress. Nolan (2015) also projects that, on average across the IOI, the growing season will increase by 35 or 40 days based on low to medium emissions or high emission scenarios, respectively. At the other end of the scale, heavy rainfall events are expected to increase by around 20%. This could lead to flooding and waterlogged pastures, both of which will negatively affect production.

Due to the importance of a favourable climate for agricultural production, there are innumerable risks associated with climate change. Projections suggest that climate change will lead to a more volatile climate, with the extremes changing much more than the averages. Also, heavy rainfall events that could cause flooding and droughts are likely to increase in prevalence and severity. It is important to determine the potential for such events to occur. This is so that mitigation measures can be identified that could lessen the effect of any vulnerabilities to extreme weather within the dairy production chain.

3.4 Mapping the dairy supply chain

An agricultural supply chain can be defined as extending from "farm to fork". The dairy supply chain consists of different stages all contributing to the final supply of dairy products to the consumer. For the purposes of this study the stages, products and services and the actors in the supply chain are adapted from Heery et al. (2016), Le Heron et al. (2010) and Jaffee et al. (2010).

The stages of the supply chain are shown in Figure 3.4. They are

- Inputs
- Production
- Primary and secondary processing
- Marketing and distribution
- Retail.

At each stage actors contribute products or services complementing the flow of goods and materials. Financial flows run back up the supply chain from the consumer, and information flows in both - directions between consumers and producers.

The supply chain is embedded within an enabling environment at both a domestic and international level. At a domestic level, actors are influenced by matters such as policies, institutions and regulatory frameworks. Trade regulations and agreements and trading partners' policies influence the supply chain at an international level.

A detailed description of each stage of the supply chain is available in Appendix 2. A brief overview is provided here.

3.4.1 Inputs

The production and distribution of material inputs to farms is the first stage in the dairy supply chain. Inputs to dairy production fall into two categories:

1. Pasture-related inputs. These include land, infrastructure (e.g. buildings and facilities), fertilisers and fuel.
2. Animal-related inputs. These include stock, feed, electricity and veterinary services.

Feed, fertiliser and energy are the most important inputs for the production of milk. Actors associated with these inputs include equipment vendors, fertiliser and feed suppliers and veterinarians.

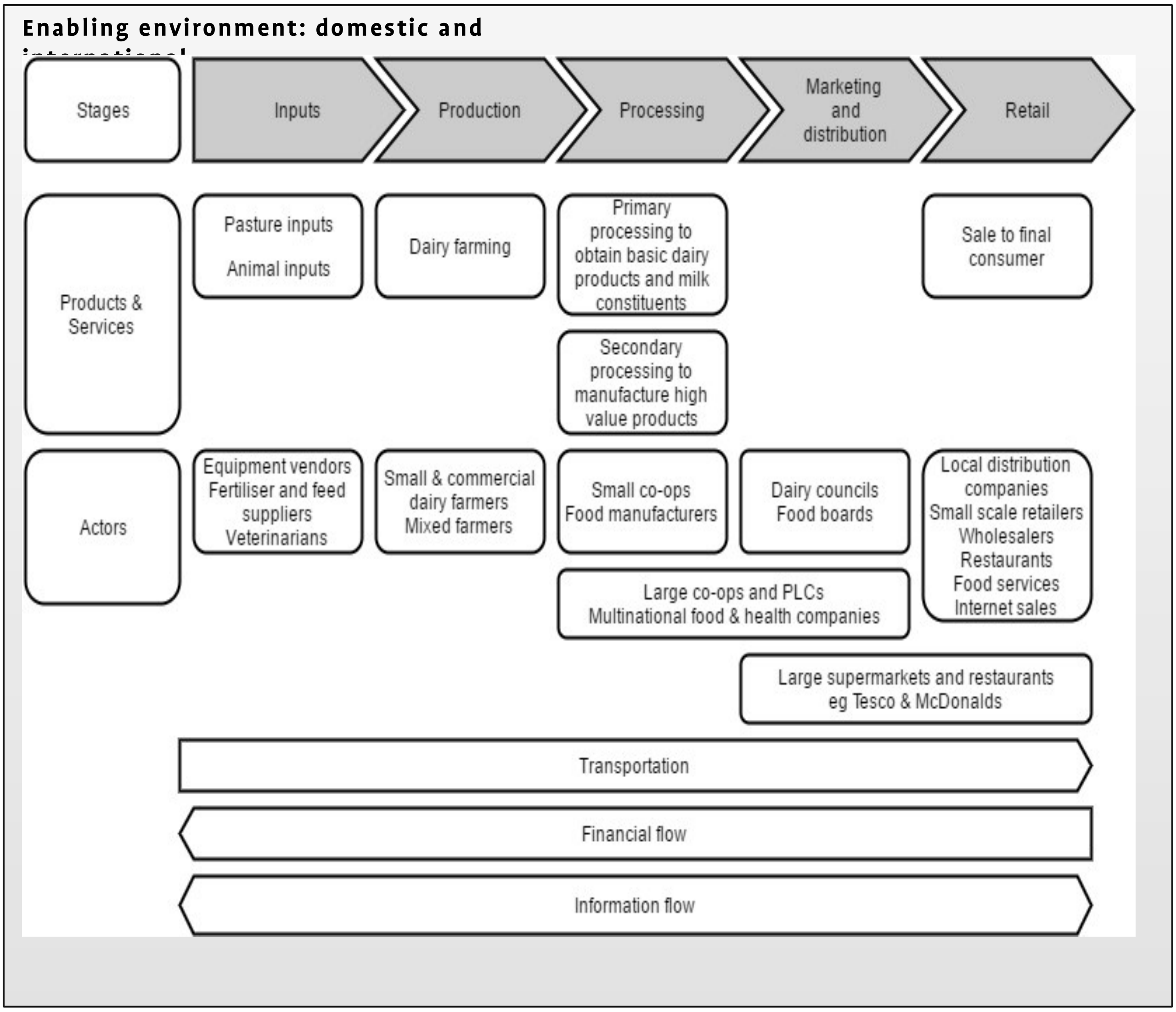
The dairy production system in both the ROI and NI is considered to be grass-based compared with the systems in other competitor countries, which in many cases are largely grain-based. Even so, 64% of the ROI's dairy herd feed requirements are imported. The ROI uses grass as a feed source more than in NI where purchased compound feeds make up an even greater proportion of the cow's diet. Therefore, farmers in NI are more exposed to changes in animal feed price. Farmers in the ROI are more exposed to the local weather conditions (because there is a production risk associated with variable levels of grass growth) and to changes in fertiliser prices.

Fertiliser is the second most significant input to milk production on the IOI and none of this is manufactured on the island. Phosphate rock is one of the main components of phosphorous-based fertilisers and because it is non-renewable it is a long-term threat to the dairy production system on the IOI.

Energy, in the form of electricity and fuel, is a major input in milk production. Electricity is a used in on-farm milking and chilling processes and so farmers are exposed to energy price volatility.

Water is also an important input in milk production. Murphy et al. (2014) found that around 6.4 litres of water is used on ROI dairy farms for every litre of milk produced. As most of the present water supply is obtained from surface water, with up to 25% coming from groundwater, rainfall is extremely important.

Figure 3.4: Dairy supply chain



Source: Adapted from Heery et al., 2016, Le Heron et al., 2010 and Jaffee et al., 2010).

3.4.2 Production

The production stage of the dairy supply chain consists of primary agricultural production, also known as the “farm sector”. On the IOI, the actors at this stage are a large number of commercial dairy farmers of moderate scale. Milk production in NI totalled 2,266 million litres in 2015 and was produced on 2,655 farms (DAERA, 2016). This was valued at £479.9 million at the farm gate, in other words, the net value of the milk to the farms that produce it. The ROI produced 6,395 million litres in 2015 from 15,588 farms (Central Statistics Office [CSO], 2016; Teagasc, 2016). The size of the average dairy herd differs between the two jurisdictions. There is an average of 70 cows per farm in the ROI and in excess of 100 in NI (Hennessy and Moran (2015); DARD, 2015).

Milk production is highly seasonal in the ROI with over one third of the annual milk supply delivered between May and June. Milk production in NI also has a seasonal peak but it is much less pronounced than in the ROI. Dairy farming is quite concentrated regionally on the IOI with almost two-thirds of the dairy cows found in just three regions: 46% of the dairy herd of the IOI is divided between the southeast and southwest of the island, with 19% of the dairy herd located in NI.

3.4.3 Processing

The processing stage involves the transformation of raw materials into one or more finished products. The main actors at this stage of the supply chain are milk processing companies. On the IOI most of these companies have a co-operative ownership structure. They are owned by the farmers and, although people are employed to carry out management functions, farmers retain key decision-making roles. This form of "vertical integration" into the supply chain – where a company combines two or more stages of production that are more often undertaken by separate firms – gives farmers more market power within the supply chain.

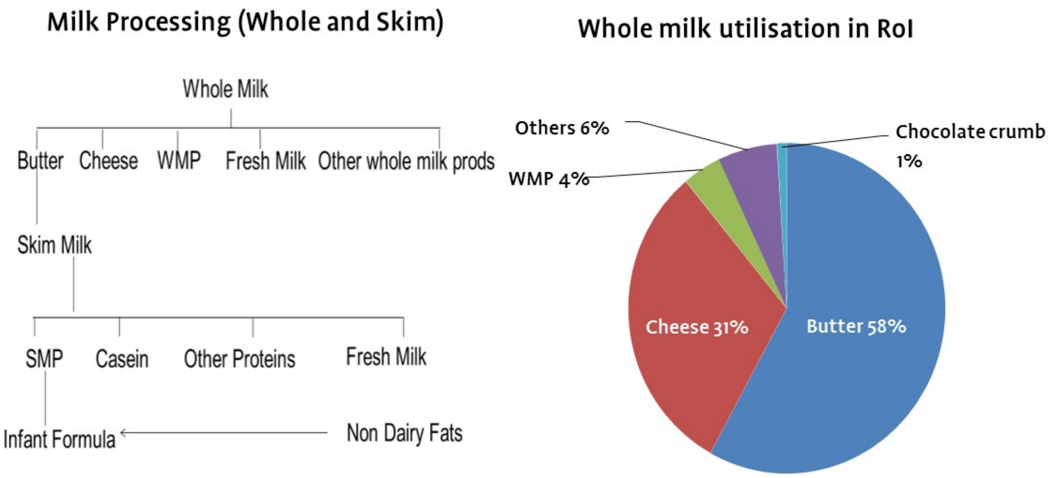
There are 16 processors in the ROI, with the six largest processing more than 80% of the milk pool. In NI there are 12 processors, with eight processing more than 80% of the milk pool. Some milk processors operate in both jurisdictions, with little of the milk processing capacity in NI actually owned or controlled by NI dairy farmers.

Dairy processing involves preparing liquid milk for human consumption and the separation of its different constituents for the manufacture of other dairy products such as butter, cheese and whey powder. Some of the products obtained from the first stage of processing go on to secondary processing to create higher-value products such as infant formula, sports nutrition products and confectionary. These products are made using either whole or skim milk, as can be seen in Figure 3.5.

Just 8% of the milk pool in the ROI is used for the liquid (drinking) milk market. Over half of the whole milk is used for the production of butter. Skim (skimmed) milk is a by-product of the creation of butter and cream. This is converted to skim milk powder (SMP) and other protein-based dairy products. Nearly half of all skim milk is used for the production of proteins such as casein and caseinates. The remainder is split between SMP and other skim milk products.

Technological advances in processing have increased the range of goods processors can make. This allows producers to branch into sectors that allow for higher profit, such as infant milk formula and sports nutrition drinks.

Figure 3.5: Milk processing and product utilisation in the ROI



Source: Hennessy and Moran (2015). Whole Milk Powder (WMP)

3.4.4 Marketing and distribution

This stage of the supply chain involves shipping dairy products from processing plants to retailers or to other businesses along the food chain. The main actors at this stage are dairy processing companies that are integrated across the supply chain, and export agencies. As a share of total milk production domestic consumption of dairy products on the IOI is relatively small at less than 20%, and rapidly declining. Therefore, the export market is the main outlet.

In the ROI the marketing and distribution of dairy products internationally is conducted for the most part by the three largest processors (Glanbia, Dairygold and Kerry Group) and Ornua (previously known as the Irish Dairy Board). A privately owned dairy export co-operative, Ornua also conducts a certain amount of marketing and distribution on behalf of large processors.

Dairy products are exported from the ROI to over 130 markets worldwide. The top five export destinations are the UK, China, the Netherlands, Germany and the US. Butter, cheese and infant formula are the three highest value export products. The principal milk products produced in NI are milk powders and cheese. Around one third of NI's milk production is exported to the ROI for both processing and drinking milk use.

3.4.5 Retail

Purchase by the consumer is the final step in the supply chain. This includes retail and catering sales as well as sales of ingredients to other food manufacturers. A relatively small proportion of the dairy products produced in both the ROI and NI is consumed by the home market.

A large portion of the retail activities within the IOI are undertaken by large multinational supermarkets. These supermarkets take part in the marketing, distribution and sale of the final product. This allows them substantial control over the supply chain, especially in the case of liquid (drinking) milk, which is the most consumed dairy product in both jurisdictions.

3.4.6 Transportation

Transportation is required throughout the supply chain to move goods to the next stage. This includes getting inputs to the farm, transportation of milk from the farm to processing facilities and final transportation of finished products to their destination within the IOI or internationally.

Milk is generally transported from farms to the processor in milk tankers. A survey found the weighted average milk transport cost[6] in the ROI to be 1.15 cent per litre (Quinlan et al., 2005). These transportation costs will be affected by the price of fuel, which has been quite variable over the last decade.

However, many other factors influence the cost of transport at this stage of the supply chain. These include the distance between farms and processing plants, truck and tanker size, frequency of collection, seasonality of milk production, labour costs, route management and interest rates, among other things (Quinlan et al., 2010). Drawing from the various descriptions above, Heery et al. (2016) produced a detailed map of the dairy supply chain of the IOI (Figure 3.6).

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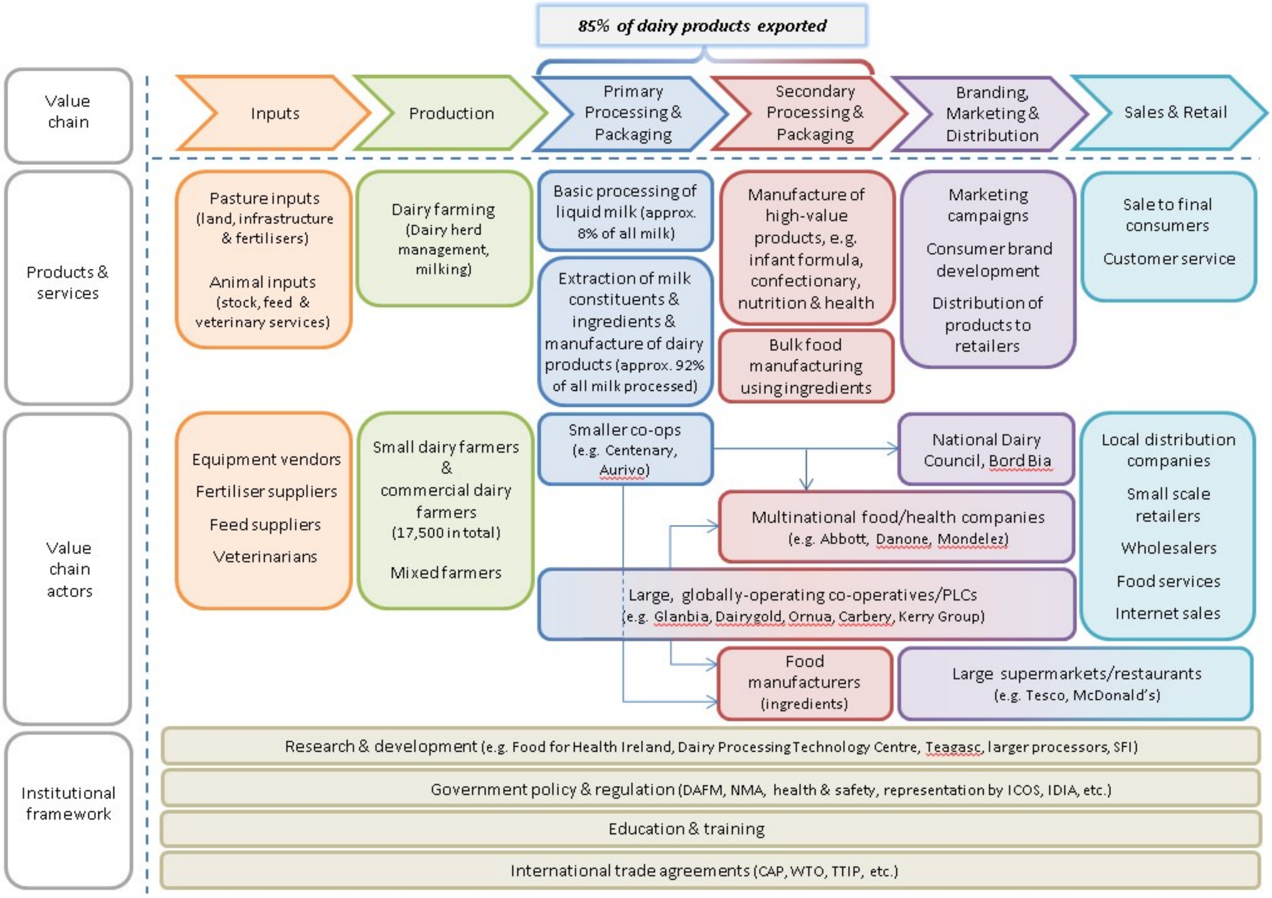
[6] Weighted average costs are calculated by dividing the total cost of units for sale by the number of units for sale.

Figure 3.6: Map of the dairy supply chain in the ROI



Source: Heery et al., 2016.

3.4.7 Conclusions on the dairy supply chain

In terms of both input requirements and destination markets, the dairy sector on the IOI is highly reliant on trade. The IOI is also completely dependent on imported fertilisers since no production facility exists on the island. A high share of the feed used on dairy farms is also imported, particularly protein-based feeds such as soya. The home market is small relative to the volume of milk produced and therefore most of the milk will be consumed elsewhere.

Dairy farmers have a degree of input into the management of processing facilities. This is due to the prevalence of the co-operative model of ownership within the dairy sector. The dairy product mix (the different milk-based products that can be made) is weighted towards dairy commodities, with price being a key selling point for international buyers.

3.5 Climate change risk assessment

The general prediction for the impact of climate change is that summers will become hotter and winters milder (Dunne et al., 2009). Precipitation on the IOI is predicted to fall by 25 to 40% during the summer months and to increase by 10 to 25% during the winter months (Stewart and Elliott, 2015).

To determine what climate change risks may be relevant to the dairy supply chain, the Rapid Agricultural Supply Chain Risk Assessment (RapAgRisk) was used. The assessment focussed on the risks from altering climate patterns to individual geographical areas and to actors in the supply chain. This method of assessing risk was devised by the Agricultural Risk Management Team of the World Bank (ARMT). Its primary objective is to help decision makers understand the exposure of the different actors in the agricultural supply chain to risks, and to improve upon risk management strategies (Jaffee et al., 2010).

The RapAgRisk methodology was applied to the dairy production chain through a detailed literature review, which analysed all sectors of the chain: input supply, production, processing, transport and distribution and sales and retail (Jaffee et al., 2010). The dairy supply chain was broken down into stages, reviewed and analysed, with potential vulnerabilities to climate change effects identified through use of the RapAgRisk indicators.

Identifying potential impacts of climate change is essential to help dairy producers, processors and distributors to be aware of the risks posed to their industry and to plan for them. The identification of probable risks along the dairy supply chain may inspire the promotion of both mitigation and climate change adaptation measures throughout the supply chain. In addition to assisting the producers in the dairy supply chain, climate change risk identification can also contribute to the development of new national policies on adaptation. The exercise can also provide an assessment of supply chain sustainability and resilience in the face of climate change events such as flooding and heatwaves.

The implementation of global policies and frameworks, such as the Kyoto Treaty, European Commission Climate and Energy Package 2020 and the EU Climate and Energy Framework 2030, set out binding targets for GHG emission. The implementation of these policies can have a knock-on effect on dairy production on the IOI.

Flooding and heatwaves are examples of direct climate change impacts. They result from fluctuations in weather patterns and extreme weather events. Indirect impacts can result from economic issues arising from the direct impacts, such as loss of productivity, or from pest or disease development on crops as ecosystems adapt to a changing environment (Watts et al., 2015).

A less severe indirect impact to note is the application of national and European climate change policies. For example, policy implementation designed to adapt to, or mitigate against, direct climate change impacts may influence dairy and other agricultural production because reduction targets for

GHG emissions will result in lower consumption of fossil fuels with more emphasis on renewable energy use and development.

Table 3.1: Categories of major risks to agricultural supply chains from climate change

Type of Risk	Examples
Weather-related risks	Periodic deficit and/or excess rainfall Excessive temperatures Hail storms Strong winds
Natural disasters (including extreme weather events)	Major floods and droughts Hurricanes, cyclones and typhoons Earthquakes Volcanic activity
Biological and environmental risks	Crop and livestock pests and diseases Contamination related to poor sanitation, human contamination and illnesses Contamination affecting food safety Contamination and degradation of natural resources and environment Contamination and degradation of production and processing systems
Market-related risks	Changes in supply or demand that impact domestic or international prices of inputs or outputs Changes in market demands for quantity or quality of product attributes Changes in food safety requirements Changes in market demands for timing of product delivery Changes in enterprise or supply chain's reputation and reliability
Logistical and infrastructural risks	Changes in transport, communication or energy costs Degraded or unreliable transport, communication or energy infrastructure Physical destruction Conflicts Labour disputes affecting transport, communications and energy infrastructure and services
Management and operational risks	Poor management decisions in asset location and livelihood or enterprise selection Poor decision making in use of inputs Poor quality control Forecast and planning errors Breakdowns in farm or firm equipment Use of outdated seeds Not being prepared to change product, process or markets

	Inability to adapt to changes in cash and labour flows, and so on
Public policy and institutional risks	Changing or uncertain monetary, fiscal (governmental finance) and tax policies Changing or uncertain financial (credit, savings and insurance) policies Changing or uncertain regulatory and legal policies and their enforcement Changing or uncertain trade and market policies Changing or uncertain land policies and tenure (land occupation) system Governance-related uncertainty (e.g. corruption) Weak institutional capacity to implement regulation
Political risks	Security-related risks and uncertainty (e.g. threats to property or life) associated with politico-social instability in a country or in neighbouring countries Interruption of trade due to disputes with other countries Nationalisation or confiscation of assets, especially for foreign investors

Source: Jaffee et al., 2010.

Most of the risks identified are to the production stage of the supply chain. A dairy farm is greatly influenced by climate, especially on the IOI where the dairy industry is highly reliant on grass. Climate change will indirectly affect dairy production through effects on grass production and effects at farm level will be felt throughout the supply chain (Silanikove and Koluman–Darcan, 2015). This will influence the level of inputs needed and the level of production and quality of milk available to process and sell to consumers.

For each category, the risks were identified along with what their impact could be and why it is important. The risks were identified through an investigation of the literature on this topic. For a more detailed discussion of each risk, see Appendix 3. A summary is provided here.

3.5.1 Weather-related risks

Changes in weather, be it gradual warming or an increase in extreme weather events, directly impact the production stage of the dairy supply chain. For example, grass growth is expected to be positively affected by the increase in temperature and CO_2 quantities and the reduced number of frost days. CO_2 concentration has seen a continued increase from the pre-industrial time and is now higher than ever (Miraglia et al., 2009). However, the southern part of the IOI may be affected by increased dry periods and drought, and periodic irrigation (watering) may be required. As such, climate change may present a threat to or opportunity for grass production. Heat stress for animals is another potential direct threat that may cause a reduction in yield and milk quality.

Climate change may have a greater adverse impact on milk production in other countries and this may present opportunities for both ROI and NI producers. For example, if grass and crop production are negatively affected or heat stress of animals becomes a major problem in these countries, then global milk production is likely to decline. In this case producers on the IOI may have the opportunity to grow their market share or to sell products at a higher price.

3.5.2 Natural disasters

It is likely that climate change will lead to an increased frequency and intensity of weather-related natural disasters such as floods, storms and droughts. Morris and Brewin (2014) identified different impacts of flooding on farms. These include the need to evacuate livestock to housing or flood-free areas, damage to pastures and grass production, reduction in crop yields, damage to drainage systems and field infrastructure, loss of beneficial soil biodiversity and an increased risk of animal disease.

Related expenses could include, for example, the cost of purchasing feed, reseeding pastures, repairs to farm gates and drainage systems and the use of machinery to clear debris left behind. However, input suppliers may benefit from flooding on farms as the demand to carry out repairs and improve flood defences, as well the requirement to purchase feed, will increase.

3.5.3 Biological and environmental risks

Biological risks are generally associated with reductions in yield and quality. Increased consumer awareness of the environmental footprint of agricultural products is becoming a risk to downstream (secondary) processors and distributors. Pests and pathogens have a negative effect on both animals and crops. Climate change may result in a changing ecosystem where both pests and pathogens thrive, including mycotoxins. Animal-related pests and diseases will increase the need for veterinary services and possibly more livestock inputs if they become a serious problem.

3.5.4 Market-related risks

Market-related risk occurs due to changes in supply and demand. This can alter both the inputs to and outputs from the producer. These issues can affect the price, quality and availability of products and services needed, as well as access to them. Global projections on changes in crop production due to climate change vary and the impact will largely depend on the level of adaptation within the industry. Animal feed prices are volatile and climate change will add to this instability, increasing price fluctuation at the input stage of the supply chain.

The expected increase in human population and rising incomes in developing countries are expected to contribute to an increase in demand for dairy products. However, there is some concern from within the dairy sector that consumers will consider the carbon footprint of dairy production and consequently reduce their demand for dairy foods. Arguments have been put forward for a global reduction in the consumption of meat and dairy products in order to reduce GHG emissions and associated environmental impacts. Currently, there is no evidence that this is significantly affecting demand. However, as the effects of climate change become more obvious to the public this may change consumer behaviour. If such a reduction in demand were to occur on a global scale, it would lead to shrinkage of the IOI dairy supply chain due to the predominantly export-based nature of the sector.

3.5.5 Public policy and institutional risks

Policy and institutional risks relate to the possible implementation of laws and regulations that directly affect the dairy supply chain. With regard to climate change, this is likely to relate to mitigation strategies that attempt to control emissions and minimise impacts.

Current policy regarding climate change on the IOI is highly influenced by the EU. The recent "Brexit" vote in the UK has confirmed that the UK will leave the EU and this has clear implications for NI. The ROI government has committed to reducing GHG emissions to 20% of 2005 levels by 2020. Heavy fines must be paid if this commitment is not met. Recently, new targets have been put in place for each EU member state for the period 2021 to 2030. The ROI is expected to reduce its emissions to 30% of 2005 levels by 2030, placing even more pressure on the Irish government to meet these targets.

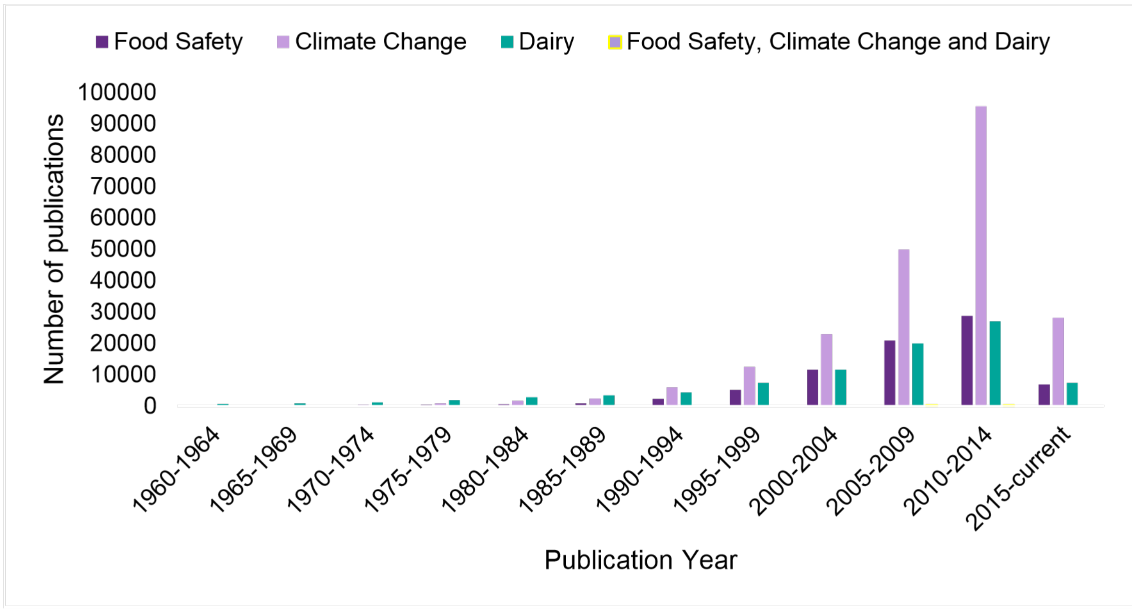
As yet there is no direct cap on emissions for the dairy sector. However, it is possible that this may occur at some time in the future. GHG emission caps or associated policies will likely place limits on the level of dairy production, or reduce profitability if it entails the purchase of emissions quotas (allowances). This uncertainty may lead to underinvestment in the dairy sector. It is conceivable that in the short term the UK will not be obliged to implement EU emission policies concerning GHGs, following its exit from the EU. That said, the export-based nature of the dairy sector means there could still be a requirement to implement similar policies to demonstrate a "carbon-proofing" of the sector because the fight against climate change is global in nature. Reform of the Common Agricultural Policy (CAP) may also present threats or opportunities to the dairy supply chain on the IOI in term of changes to the value of direct payments made to farmers and/or changes to compliance criteria relating to the environmental impacts of farming.

3.6 Climate change and food safety

For the literature review on the food safety impacts of climate change, three key terms were highlighted: “dairy”, “food safety” and “climate change”. Figure 3.7 shows the steady rise in occurrences for each search term since 1960. It is evident that there is increasing research on each theme independently over this time period but only recently has any research been conducted to examine climate change specifically in the context of dairy production.

Food safety has been steadily examined in the past 50 years. There were just 60 publications on the topic between 1965 and 1969 but there has been a significant increase in recent years with 28,757 publications found between the years 2010 and 2014. This may be due to major food safety scares such as dioxin-contaminated milk found in Germany and the Netherlands in 1998 and the Bovine Spongiform Encephalopathy (BSE) crisis that was first recognised in 1986 (Hoogenboom, 2004; Ganter, 2015).

Figure 3.7: Results of the literature search for each of the key terms from 1960 to current time



Source: Scopus, 2016.

The theme of climate change showed a similar trend of a steady increase in annual publications. In particular, since 2010 there have been 123,674 publications on the topic. This rise in interest undoubtedly reflects our changing weather patterns as extreme events increase in frequency and intensity (IPCC, 2013). The relative rapidity of such changes in weather and the global nature of their effects has led to a realisation that measures are urgently required to tackle these changes.

The increase in publications about climate change and food safety impacts shows a growing concern particularly within this combined area. Since 2009, there has been a recognition that climate change may directly or indirectly influence the development and emergence of food safety hazards (Marvin et al., 2009). If all the terms – “dairy”, “food safety” and “climate change” – are searched for together, published research only becomes available from 2005 on, with just seven publications found up to 2015. Focussed research on these three themes together therefore remains a relatively new concept within the agri-food industry.

3.6.1 Pathogens

Extreme changes in climate can affect the microbiological safety of food as they may impact on the spread of pathogens within the environment (Doyle et al., 2015). *Salmonella*, *Mycobacterium avium* subspecies *paratuberculosis* (MAP), Verotoxigenic *Escherichia coli*, *Listeria monocytogenes*, *Mycobacterium bovis*, *Staphylococcus aureus*, *Yersinia enterocolitica*, *Clostridium botulinum* and *Bacillus cereus* have been highlighted as concerns for the dairy industry. These pathogens may be passed through the food chain if monitoring and control measures are not sufficient (Stewart and Elliott, 2015; Grant et al., 2002; Food Safety Working Group, 2011; Scallen, 2011). In reference to the economic burden of foodborne illness, Scallen and co-workers (2011) have rated *Listeria* as one of the costliest.

Human infection caused by consumption of *M. bovis* has been largely controlled through pasteurization of milk and compulsory tuberculin testing of cows. In the period 1990 to 2003 between 17 and 50 cases of human *M. bovis* infection were confirmed each year in the UK (de la Rua-Domenech, 2006). This is evidence that although the pathogen may not be a current threat, changing climate may give rise to new opportunities for disease. *S. aureus* was highlighted as a potential contaminant that may be present in raw milk (Stessl and Hein, 2010) and *Y. enterocolitica* was also recently found in raw milk samples, particularly from cows (Jamali et al., 2015). Another pathogen of interest found in the literature was *C. botulinum*. It can occur mainly in cattle after ingestion of spores, followed by colonisation of the animal’s intestines (Fohler et al., 2016). The pathogen can exist there without causing disease in the host animal.

B. cereus is a potentially problematic pathogen that can grow in foods with low acidity, such as milk products. Evelyn and Silva (2015) state that, to inactivate the psychotropic (mood- or mind-altering) spores, high-pressure processing (HPP) along with thermal processing must be used. This technology may have wider application within the dairy sector for the overall control of *B. cereus*.

Brucella abortus and *Brucella melitensis* are pathogens that stem from the same family (Brucellosis) and are reported to be endemic in both livestock and humans. Transmission occurs through milk consumption from infected cattle (Mugizi et al., 2015). With no vaccine currently available for humans who may consume these pathogens, prevention relies heavily on control in the animal (Godfroid et al., 2011). There is some concern about the challenge these pathogens may present for the dairy sector in the future.

Pathogens have the ability to survive in the environment for long periods, allowing them to multiply rapidly. Miraglia and co-workers (2009) outline that the survival of harmful pathogens in the environment is important for bacterial transmission, which can contaminate food and water. This suggests that as environmental conditions change, so too will the transmission route of pathogens; and if conditions continue to become favourable, pathogens will readily thrive in the environment, leading to a greater risk of contamination and disease in humans.

With the wetter conditions projected during the winter months, animal disease may become an increasing problem. More veterinary medicines such as antibiotics will be required, with the potential for transmission into the food chain. Rushton and co-workers (2014) emphasise that widespread antibiotic drug use has been linked to increased antimicrobial resistance. This raises concerns about the efficiency of both animal and human medicines in the future. Other researchers reinforce this concern, adding that unknown animal diseases will also be introduced and current diseases may evolve in a different way (Van der Spiegel et al., 2012). Incidences of both foodborne infections and zoonotic disease may increase, with consequences for human health. Measures to safeguard animal health must therefore be explored and implemented to lessen the impacts of climate change on pathogen and pest biology.

Other chemical factors may also have an influence on the health of livestock. The level of use of chemicals such as pesticides, and the potential for contamination by environmental chemicals such as dioxins and polychlorinated biphenyls (PCBs) will also be influenced by climate change and may become more widespread (Rosenzweig et al., 2001).

3.6.2 Natural toxins – mycotoxins

One of the most prevalent food safety hazards within the dairy industry are mycotoxins, particularly in animal feed and mainly in the form of aflatoxins. Mycotoxins are produced as a by-product of toxigenic (poisonous) mould metabolism. Contamination of crops occurs regularly due to the mould infestation of agricultural products such as grains, fruits and nuts (Murphy et al., 2006).

Mycotoxin production is influenced by the season and weather (mainly temperature and humidity), and by the region and the method of harvest (Baranyi et al., 2015). With a projected warmer and wetter future climate on the IOI, such favourable conditions will intensify the spread of mycotoxins during harvest and storage of crops. This may also be influenced by changes in the quantity, type and location of crops grown, again a consequence of climate change (Van der Spiegel et al., 2012).

If climate change adversely affects crop yields on the IOI, there will be a greater reliance on imported feed. Such feeds may contain hazards that have not presented a problem to the dairy industry so far. More research will be required to ensure the unknown hazards are identified and accounted for, to prevent threats to both animal and human health.

Early detection and monitoring of mycotoxins is also vital for the protection of human health (Van der Spiegel et al., 2012). Schmidt (2013) supports this view and claims that human exposure can be reduced through early harvesting, drying of the grain and use of storage containers to minimise moisture and temperature conditions that favour toxin growth. New technology and monitoring systems must be developed and implemented to arrest any mycotoxin hazard before it enters the dairy food chain. However, such systems will involve a high cost that will necessitate a collaborative (collective) effort to ensure full acceptance and implementation throughout the chain.

Schmidt (2013) describes aflatoxins as the most powerful naturally occurring liver carcinogen ever identified. Their ability to infect maize, nuts and other crops used in feed make cattle particularly susceptible to aflatoxin exposure. Fungal contamination of crops increases with drought stress and intense heat, which are projected to become more frequent and intense as a result of climate change (Schmidt, 2013). Prolonged hot and dry weather has already caused outbreaks of moulds leading to aflatoxin contamination in Europe during 2003 (Miraglia et al., 2009). As the climate continues to change and create drier and warmer periods, the risk of aflatoxins becomes more apparent. Aflatoxin B1 is one type of mycotoxin that poses a threat to the dairy industry. The toxin is readily metabolised to aflatoxin M1 which is detectable in milk after cattle are fed contaminated feedstuffs (Prandini et al., 2009).

Fumonisins are also a concern. The growth of fusarium mould and fumonisin production are favoured by dry weather conditions during grain fill and by late season rains (Munkvold and Desjardins, 1997). Given the climatic predictions for the immediate future, the risk of fusarium contamination and fumonisin toxin production may increase.

Zearelenone and deoxynivalenol (DON), T2 and HT2 are other mycotoxins that have been highlighted as a concern in the literature, affecting cereal grains such as maize and wheat (Miller, 2008; van der Spiegel et al., 2012). Studies carried out on cereal grains found DON to be particularly problematic. It is found in 46% of wheat, oat and maize samples (Van der Fels-Klerx et al., 2012). Zearalenone was also observed in wheat and the presence of both these mycotoxins increased with higher temperatures, increased rainfall during harvest and relative humidity. This indicates that climatic changes will benefit the growth of certain mycotoxins in cereal grains.

Cereal grains are used for livestock feed and so the presence of mycotoxins will increase the risk of exposure for animals (Bryden, 2012). Careful monitoring and control measures may mitigate against the presence of these mycotoxins during milk processing. Van der Spiegel and co-workers (2012) claim that cold regions may become liable to problems concerning ochratoxin A. However, climate change predictions for the IOI are for an increase in temperature, which would suggest a reduction in favourable conditions for *Aspergillus* and *Penicillium* growth and ochratoxin A production.

3.6.3 Natural toxins – plant alkaloids

Three types of plant alkaloids were highlighted in a search of the literature: pyrrolizidine, ergot and tropane. Raised temperatures are favourable for increased alkaloid concentrations (Bourguignon et al., 2015). All three types of alkaloid predominate in feeds and cereals (European Commission, 2012). Plant alkaloids are the subject of greater concern in recent years. The projected temperature increases due to climate change may lead to raised levels of these toxins in feed, with consequences for animal health and dairy production.

Secondary metabolite constituents such as lectins and saponins are also hazards relevant for animal feed. These constituents are produced by plants in response to environmental stressors (Attia, 2010). Lectins and saponins may have adverse effects on livestock performance, including loss of appetite and reduction of nutrient digestibility. It is therefore evident that these secondary metabolites may be an emerging threat to the well-being of livestock and the ongoing effects could lead to deterioration of overall animal health.

New technology and better practices may offer important means to prevent the consequences of climate change but it remains an ongoing threat. Bailey and co-workers (2014) claim that climate change prevention is unlikely to be achieved through new technologies alone, and so a shift in dairy consumption is vital. The total GHG emissions produced by the dairy sector accounts for 14.5% of the global total (Bailey et al., 2014). If dairy consumption continues to rise, more cattle will be required and more emissions will be released as a result. There must be greater emphasis on the carbon efficiency of dairy production.

3.6.4 Chemical contaminants

Due to climate change, the use of veterinary medicines and anthropogenic chemicals may increase to combat diseases and parasitic infections and to control pests. Wetter conditions could be bad for animal health, increasing the risk of disease in livestock. This will increase reliance on antibiotics and may aggravate the problem of antimicrobial resistance in the dairy industry. The potential for zoonotic (animal–human) disease transmission may increase, which could lead to harmful effects on humans (Slingenbergh, 2004).

Other veterinary drugs and their residues of concern include anthelmintics. Parasite infections such as lice, mites and coccidia limit production in cattle and lead to reduced growth, impaired fertility and death (Gordon et al., 2013). They also cost the dairy industry huge sums each year in fees associated with control measurements (Cooper et al., 2015). Control includes the use of coccidiostats that are used to combat coccidiosis in livestock bred in intensive indoor rearing systems similar to those on the IOI (Kools et al., 2008). Climate change may force a shift toward greater reliance on indoor rearing systems, which could then increase the risk of coccidiosis. This may be an emerging threat and communication initiatives may be needed to increase the level of awareness among primary producers.

To combat certain diseases, antiviral drugs and non-steroidal anti-inflammatory drugs (NSAIDs) are used in veterinary practice. Gale and co-workers (2009) state that climate change will undeniably have a significant influence on vector-borne diseases (transmitted by the bite of an infected insect) in Western Europe. Should animal viruses become endemic on the IOI, there will be increased pressure to use antiviral drugs. This is controversial. The WHO (2005) urged member states not to use antiviral drugs in food animals and to use them in human medicine only. Antiviral drug residue testing is currently not part of routine food testing programmes within the EU (Cooper et al., 2015).

On the other hand, the use of these drugs may be an effective way of eradicating some viral diseases that may also have an impact on humans. Greater exploration of new drugs, or better use of existing drugs, specifically for livestock may be necessary to further reduce the risk of antiviral drug residues entering the food chain.

There is an association between climate change and the increased use (or misuse) of pesticides. Changing weather patterns will create an increase in pest outbreaks in crops, which will result in increased use of pesticides (Hall et al., 2002). Such practices will lead to an increased risk of exposure of pesticides to animals and humans through residues in food (Rosenzweig et al., 2001). Again it is important that actors within the dairy sector are fully aware of the potential link between climate change and pesticide use.

“Heavy metals” such as cadmium, mercury, arsenic and lead may also be of concern. The literature states that heavy metals may contaminate both silage and pasture and that this is promoted by climate change (Miraglia et al., 2009; Tirado et al., 2010). Given that cattle production on the IOI is primarily grass-based, the risks of heavy metal consumption and transmission into milk may increase. Climatic changes may influence soil conditions, including heavy metal levels that could directly affect the growth of plant species. Öncel et al. (2000) report the effects of heavy metal stress due to changes in temperature that may lead to nutrient deficiency in plants. It may also result in decreased resistance of plants to certain diseases, insects and pests. If this occurs, farmers will have to use more chemical fertilisers otherwise crop yield will deteriorate. Greater use of fertilisers may lead to higher levels of trace element impurities in raw material that could enter the food chain (Miraglia et al., 2009).

Incidents of contamination with dioxins and PCB have occurred in recent times. For example, in 1998 in the Netherlands and Germany milk was contaminated by polluted animal feed (Hoogenboom et al., 2004); and in 2004 in the Netherlands milk from dairy farms was contaminated by dioxins from potatoes (Hoogenboom et al., 2010). Processing contaminants such as furan and acrylamide may affect cereal grain composition (Halford et al., 2014). The stresses of climate change can lead to the production of these chemicals in crops, which may then be passed through the food chain when consumed by livestock.

Another major contaminant that has been an issue for food safety is the chemical melamine. The Chinese milk scandal in 2008 was one of the biggest food safety crises dealt with in recent years. Up to 52,000 people were hospitalised as a result of contaminated milk powder (Pei et al., 2011). Melamine is a nitrogen-rich organic base normally used in the manufacturing of plastic. Its consumption led to widespread illness in infants, in whom kidney function is not fully developed (Ellis et al., 2012). Melamine was also detected in animal feedstuffs, which were adulterated for short-term economic gain (Ellis et al., 2012). The effects of climate change will undoubtedly create further opportunities for the fraudulent (financial) or ideological (political) exploitation of food chain vulnerabilities. This will lead to unsafe practices in food production such as that documented in the melamine event.

Perchlorate is both a man-made chemical and one that is known to be naturally present in ground water in many areas. At high concentrations, it is toxic to humans and other animals particularly through the inhibition of iodine uptake by the thyroid gland (Brabant et al., 1992). Since 1997, it has been detected in water and other media such as soil and milk (Kosaka et al., 2011). The more frequent rainfall projected with climate change could encourage the spread of perchlorate through surface runoff and the waterlogging of fields where livestock graze. This could increase the threat of intake by cattle. Perchlorate may then be passed down the food chain through cows' milk. Farmers and dairy processors will need to be informed of these hazards should the climate continue to change. New testing methods to detect this contaminant may be required to prevent transmission through the food chain and consequent human consumption.

Endocrine disrupting compounds (EDCs) are generally present in low concentrations within the environment. However, even at low concentrations EDCs may cause effects such as disruption of the immune system or reproductive function (Rhind, 2002). The potential risk for bioaccumulation in livestock might be transferred to people when they consume animal products, including dairy. It is important to understand how climate change will affect chemical pollutants such as EDCs, and how it may influence the nature of the compounds and severity of their effects.

3.7 Selection of expert interviewees

To determine the level of awareness, understanding and impact of the potential risks to the dairy supply chain on the IOI from climate change as identified from the literature search, expert interviews were conducted with dairy industry stakeholders in the ROI and NI. These were defined as representatives from each point in the dairy supply chain as well as technical experts from government departments and public sector bodies concerned with the environment, food safety, energy, food marketing and promotion, enterprise development and knowledge transfer, as well as producer and processor representative bodies.

Following the RapAgRisk method, which identified a range of climate change risks at all points in the dairy chain, the chain was separated into five categories:

1. Inputs: feed (homegrown or sourced on the IOI), feed (imported), fertiliser, fuel, animal stock and animal genetics
2. Production and processing
3. Distribution
4. Branding, sales, retail and the consumer
5. Food safety and analysis.

The potential risks and associated vulnerabilities were identified for each category with the aim of having at least one expert selected to comment on each risk. Following the establishment of this broad expert selection framework, lists of potential interviewees were generated from an internet search and from experts known to the report authors.

Initial contact was made by email, in which the objectives of the study and the project consortium (the individuals and organisations involved in conducting the research) were outlined. Arrangements were then made to conduct one–to–one interviews. In total, 20 interviews were conducted. All interviews took place at the interviewees' place of work or other location of their choice. Four interviews were conducted by phone. The interviews were based on a pre-defined survey (Appendix 4) that included closed questions, attitudinal questions scored on a Likert scale, and open-ended questions. Not all interviewees answered all of the questions. The selection plan for the interviewees is outlined in Figure 3.8.

Figure 3.8: Process of selection of experts for interviews

3.7.1 Summary outcome of expert interviews

More than 25 hours of interviews with 20 stakeholders, six of which were based in NI, were conducted during the course of this project. Many opinions were expressed and issues raised, summarised here. One of the major objectives of the interviews was to ask stakeholders to rank the climate change drivers that were identified from the literature in terms of the potential threat to their business. A scale of one to seven was used, with seven representing the greatest level of threat. The scores were aggregated (combined) and the drivers ranked in order of importance. Table 3.2 outlines the results of this process. It is important to note that the average ranking reported in this analysis may conceal the diverging views of stakeholders in different parts of the supply chain. Although that information is available, given the small size of the sample it is not practical to present a more detailed breakdown of the data.

Interviewees identified extreme weather events as the most significant threat to their business arising from climate change (average score 4.7), with up to seven out of 20 strongly agreeing and no one disagreeing. The negative impact that climate change may have on the availability and price of animal feed was identified as the second most significant threat. The rankings of the remaining threats are outlined in Table 3.2. While the score for the impact of policies averaged 3.9, it is notable that the same number of interviewees strongly agreed and disagreed that this was a threat. Heat stress was clearly identified as the least significant threat, with only one of those interviewed agreeing that it was a threat to their business.

Table 3.2: Ranking of climate change drivers in terms of potential impact on the diary supply chain

Rank	Risk	Score
1	Impact of extreme weather events	4.7
2	Impact of increased animal feed prices	4.6
3	Changes in fodder and grass production	4.0
3	Emergence of new diseases and pests	4.0
3	Consumer concerns negatively impacting on consumption	4.0
4	Policies aimed at reducing GHG emissions	3.9
5	Impact of heat stress on animals	2.0

A second major objective of the interviews was to ask stakeholders to rank mitigation strategies in order of their perceived effectiveness. Stakeholders were asked to identify on a scale of one to seven if they agreed or disagreed that particular mitigation strategies would be effective. Table 3.3 outlines the results of this ranking process. Improved animal genetics and publically provided training on methods to reduce their carbon footprint were the top two mitigation strategies selected by stakeholders. Unsurprisingly, stakeholders identified efforts to encourage a reduction in the consumption of dairy products as the least useful mitigation strategy.

Table 3.3: Ranking of suggested mitigation strategies

Rank	Risk	Score
1	Improved animal genetics to reduce emissions	5.8
1	State-provided training on means to reduce carbon footprint	5.8
2	Increased forestry for carbon sequestration	5.2
3	Incentives for producers to reduce their carbon footprint	5.0
4	Efforts or policies to reduce consumption of dairy products	1.5

A majority of the ROI interviewees agreed that the ROI would struggle to meet its obligations to reduce GHG emissions. They also agreed that the Sustainable Dairy Assurance Scheme was a positive development for the sector and that the ROI was well placed to cash in on its relatively low carbon footprint and green image.

All interviewees were asked a number of open-ended questions. Six main themes emerged, which are summarised here. Specific quotes supporting each of the identified themes are provided in Appendix 5.

3.7.1.1 Theme 1: The level of awareness of both climate change and the need for collective action is high

The interviewees from all stages of the supply chain demonstrated a high level of awareness of the issue of climate change and its potential impacts on the dairy sector. Nine of the 20 interviewees said that they felt that Irish dairy processors were very aware of climate change. Three referred to the role that Origin Green plays in promoting the issue of climate change and sustainability to dairy and other processors. Two dairy processors discussed the climate change committees and working groups brought together and supported by the Irish Co-operative Organisation Society (ICOS) and the Irish Dairy Industries Association (IDIA). They talked about how these groups are helping to communicate knowledge of climate change research to dairy processors in the ROI.

An interviewee involved in the farm inputs sector of the dairy production chain discussed the Greenhouse Gas Reduction Strategy and Action Plan, which is directed by the Department of Agriculture, Environment and Rural Affairs (DAERA) in NI. They talked about the role this action plan plays in helping farmers in NI improve their carbon intensity levels[7]. Three out of five dairy processors interviewed had some form of renewable energy technology operating in their plant: biomass boilers and Combined Heat and Power (CHP) systems[8].

There was broad agreement among all of the interviewees that the responsibility for dealing with climate change should be shared by everyone along the supply chain.

3.7.1.2 Theme 2: Climate change may present an opportunity for the IOI dairy sector

Many stakeholders were of the view that climate change may present an opportunity for the IOI to develop and expand its dairy industry. This is largely due to the projected wetter and milder weather patterns for the region that would facilitate grass growth. Furthermore, the IOI has a relatively low

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[7] Carbon intensity is the amount of CO_2 released per unit of produce – for example, per litre of milk.

[8] Biomass boilers are fuelled by organic matter and waste material. CHP systems capture and reuse the heat generated by electricity production rather than emitting heat as waste.

carbon footprint for milk production by international standards. This can be a selling point for IOI dairy products. The potential for a "win–win" scenario for dairy farmers, in which farmers can adopt technologies that will both increase their economic performance and reduce their carbon footprint, emerged as a strong theme in the interviews. However, some stakeholders raised the point that this message is not effectively communicated to or accepted by farmers.

Ten of the 20 interviewees referenced the Origin Green programme directly. This occurred when discussion arose regarding the dairy processors' awareness of climate change, the role of research in the dairy sector and the marketability of Irish dairy products nationally and overseas. These interviewees were from all stages of the dairy supply chain. Two were based in NI and identified the Origin Green programme as a model for the successful "eco-messaging" and marketing of dairy products.

3.7.1.3 Theme 3: Climate change may present a threat to the supply chain

Altering climate patterns can facilitate the migration and rapid increase in numbers of various pests or disease pathogens to new regions outside their normal geographical range. This presents a threat to animal and plant health on the IOI both directly and indirectly by impacting on the global supply chain, particularly the supply of grains and other raw materials imported into the IOI for use in animal feed.

Four of the interviewees cited the risk of impacts of climate change upon food safety as a serious threat to their sector. One interviewee discussed the issue of feed contamination in depth. They gave an insight into the "Food Fortress" programme developed at Queens University Belfast, which involves collaborative industry-wide strategic sampling of imported raw feed materials and finished feed products.

Climate change research specific to the island of Ireland is ongoing. However, projections indicate that Ireland's temperate climate will experience more moisture in autumn and winter months and drier summer months by the end of the 21st century. Extreme rainfall events over the past few years have led to sustained flooding in different parts of the island. This can adversely affect the capacity and capability of milk production. A number of interviewees stated that providing assistance to the dairy production chain in times of extreme weather events would necessitate a proactive planning strategy to help minimise the impacts. In other words, mitigaion measures should be identified and preparations made before the expected extreme weather events happen, rather than simply responding to the events after they have happened.

3.7.1.4 Theme 4: The challenge of putting research into practice

Almost half of the interviewees regarded the role of science and research in helping the dairy sector to adapt and mitigate the potential impacts of climate change as “highly important” or “critical” to the sector. One interviewee noted in particular the research and development of new formulations of fertiliser that emit lower quantities of N_2O than standard fertilisers. Four other interviewees (three researchers and one processor) mentioned the important ongoing research into CH_4 capturing technologies and methods to reduce CH_4 emissions generally. Another researcher who was interviewed spoke of the role that genetics may play in assisting the dairy sector to adapt to climate change. They also talked about the development of gene editing technologies that can help to generate new crossbreeds of dairy cattle that are more adaptable to future climatic conditions.

However, five interviewees (two dairy processors, two researchers and one policy advisor) highlighted the gap between research and the practical implementation of research outputs on a day-to-day working farm. Although there is significant investment into research on sustainable farming, it was felt that some of this may be disconnected from real life farm operations. This perceived detachment between farmers and researchers indicates a need for more effective face-to-face communication and understanding between stakeholders in the sector.

Interviewees identified distinctly different groups of farmers. Some farmers are engaged with research and education and are willing to implement abatement technologies (pollution or harm reduction technologies). Other farmers are not engaged with the process. There was broad agreement among the interviewees that the utilisation of farmer peer groups is vital in conveying relevant information to farmers. This is particularly important in the case of those farmers who seem disengaged or perhaps even disillusioned with new technology. Some questions raised by the interviewees include

- What are the impediments (barriers) to farmers’ understanding of the “win-win” concept?
- Are there effective tools in place to assist producers in adopting more sustainable work practices?
- Do farmers have the support they need to take on new technologies?
- How, and when, will famers see the financial benefits of implementing new technologies?

3.7.1.5 Theme 5: Policies relating to climate change are a concern for the sector

Uncertainty regarding future climate change policy development, particularly policies developed in a global context, is an issue for the dairy sector. Interviewees expressed the view that there was a lack of “respectful” consultation with all actors in the dairy supply chain with regard to policy development. A number of interviewees expressed concerns about carbon leakage in the context of global emissions control policies. Some of the topics that emerged from the interviews included

- A lack of a proactive approach within the sector towards tackling climate change issues (referred to by three interviewees, all researchers)

- The possibility that the implementation of future climate change policies could become the new quotas for dairy farmers (referred to by three interviewees from the processing sector)
- Fear of potential policies that are poorly thought out and that could damage the productivity of the dairy sector (referred to by two interviewees, one from the processing sector and one researcher).

The vast majority of participants disagreed quite strongly with any policy to reduce dairy food consumption in order to mitigate GHG emissions.

3.7.1.6 Theme 6: Forestry as a mitigation strategy

A number of interviewees recognised the carbon sequestration potential of forested areas[9]. However, just three interviewees (all based in NI) discussed the potential for carbon sequestration that exists in soils and the important role that land management plays in this regard. Interviewees based in the ROI appeared more focussed upon the carbon sequestration potential of trees and forested areas.

Another discussion topic that emerged in two of the interviews was the concept of diversifying dairy farm incomes through the establishment of a secondary enterprise or business, with agroforestry being one of the options put forward. The idea is to reduce the level of risk to dairy farmers' incomes from the effects of adverse weather events by creating another income stream. The application of Light Detection and Ranging (LiDAR) technology, which can help to quantify the carbon sequestration of woodlands and hedgerows on IOI farmland, was also raised by two interviewees.

[9] Carbon sequestration is a process in which carbon dioxide, a greenhouse gas that contributes to global warming, is drawn from the atmosphere and stored by trees.

4 Conclusions

The recent scrapping of the milk quota system in the EU presents an opportunity to expand milk production on the IOI. However, one of the key challenges that the IOI dairy sector is likely to encounter in future years is that of climate change. Agriculture is one of the most climate-sensitive industries on the island. It is therefore essential that, as the dairy industry expands, key stakeholders across all stages of the production chain are aware of the potential impacts of climate change. It is also crucial that potential mitigation strategies are identified and their likely effectiveness considered by all stakeholders.

It was in this context that this project identified, from an extensive literature review, key climate change vulnerabilities in the dairy production chain on the IOI. A series of semi-structured interviews were conducted with key stakeholders from the various stages of the dairy production chain to

1. Assess the relevance of each vulnerability in an IOI context
2. Rank the vulnerabilities in terms of their perceived potential threat to the supply chain
3. Assess the effectiveness of potential mitigation strategies.

It was evident from the interviews that the level of awareness regarding climate change among the various stakeholders in the dairy supply chain is high. There is agreement that collective action is required to address the issue. Climate change is viewed as presenting an opportunity by some and as a threat by others. There was general agreement that research can contribute to mitigating climate change. However, more effective communication of research ouputs and co-creation of strategies along the supply chain is required. Climate change is likely to give rise to a number of food safety threats. These include the emergence of mycotoxins in animal feed, and a greater incidence of animal diseases that may require antibiotic treatment and so add to the problem of antimicrobial resistance.

Key recommendations of the research include

- Promoting research findings more widely and encouraging the adoption of mitigation strategies
- Recognising the issue of carbon leakage when setting policy targets
- Putting systems in place to deal with the impact of extreme weather events, before they occur.

In relation to food safety it is recommended that new technology and monitoring systems be developed to ensure climate change does not become a threat, right from the start of the dairy food chain. Also, extra care must be taken to ensure any pathogens present in raw milk are eliminated through the processing phase. This will prevent the presence of pathogens in the final dairy product that would otherwise pose a threat to consumer health.

In conclusion, it is clear that climate change remains an issue for the future development of the dairy sector on the IOI. Although the level of awareness of climate change is high and the need for collective action is well understood, this project has identified a number of initiatives that could be developed to better equip the sector to deal with climate change. Importantly, the project does not address the potential impact of climate change on agri-food production elsewhere in the world including current and potential destination markets for IOI dairy products, and current or potential sources of inputs to IOI dairy production such as animal feed and feed ingredients.

5 Appendices

Appendix 1: Climate change modelling

Climate models are the main tools used to project the future climate and simulate the impact of GHGs. Uncertainty arises from both the capacity of the models to accurately simulate the effects of GHGs and the unknown level of future GHG emissions. The level of emissions depends to a large extent on future population and economic growth levels.

Climate models are structured at a larger scale than that required to accurately project the effect of climate change on the IOI, which has an area of just under 84,000 square kilometres. To obtain estimates at a more refined regional scale, a certain amount of downscaling must be carried out. The two main methods for doing this are

1. The dynamic approach, by which a regional climate model is applied using global climate model boundary conditions
2. The statistical approach, by which the large scale climate features are related to the local climate.

The IPCC (2013) states there is high confidence that downscaling adds value – it improves climate modelling – in regions with highly variable topography (different neighbouring landscapes, such as mountains, valleys and plains) and for various small-scale phenomena. Downscaling enables a higher resolution or greater detail of topography and coastlines. This is especially important in the case of the IOI, which has such a varied landscape.

Uncertainty is unavoidable in climate modelling. Fronzek et al. (2012) suggest four main sources of uncertainty.

1. The natural variability of the climate system
2. Uncertainties due to the formulation of the models themselves
3. Uncertainties in future regional climate due to the coarse (low) resolution of global climate models (GCMs)
4. Uncertainties in the future composition of the Earth's atmosphere, which affects the radiative balance of the Earth (its ability to reflect the sun's energy back into space).

To estimate future emissions, climate modellers must overcome uncertainty concerning human behavioural responses, socioeconomic change, economic growth, rates of technological development and agreements on the mitigation of emissions (Bullock et al., 2015). A common method of attempting to deal with some uncertainty is to apply an "ensemble approach". This uses multiple global climate models developed by different modelling centres. The mean, or average, of the ensemble has been shown to be more accurate than single models (IPCC, 2007). The improvement is in the verification of seasonal forecasts and the present-day climate from long-term simulations. However, this approach is still vulnerable to systematic errors (Lambert and Boer, 2001).

Under all emission scenarios, Earth's surface temperature is projected to rise over the 21^{st} century. Continued increases in GHG emissions will lead to severe and irreversible impacts for people and ecosystems. Substantial and sustained reductions of GHG emissions will be required to limit climate change risks (IPCC, 2013).

The IPCC Fifth Annual Assessment Report (2013) estimates that the global temperature will increase by 0.3 to 4.8°C by the end of the century depending on the level of GHG emissions. These temperature increases are not expected to be regionally uniform. The temperature changes are projected to be greater at higher latitudes (further north), with European mean temperatures projected to exceed the global mean. Precipitation levels are projected to increase. The IPCC states that rainfall is "likely" to increase by 1 to 3% for most of the scenarios. Studies have suggested that for each 1°C of warming, precipitation will increase by 1 to 3% (Wild and Leipert, 2010; O'Gorman et al., 2012).

The global water cycle will also undergo changes, with a greater contrast between wet and dry regions, and wet and dry seasons becoming more pronounced. The models also project that there would be an increase in the incidence of extreme precipitation events. Modelling of precipitation on a global scale runs into problems due to the sheer complexity of the physical processes and their interactions that lead to precipitation. This is compounded by the lack of sufficient model resolution (Ma et al., 2013).

A1.1 Island of Ireland and climate change

Many studies have modelled the possible effects of climate change on the IOI, using varying methodological approaches and degrees of resolution. Some studies used a small ensemble of high-resolution models (McGrath et al., 2005; Gleeson et al., 2013). Fealy and Sweeney (2008) used statistical downscaling. The majority of the projections used for this study are those made by Nolan (2015), who used an enlarged ensemble of models at high resolution including more recently developed scenarios than have been used in previous studies. The scenarios are based on Representative Concentration Pathways (RPCs) (projections of GHG concentrations that have now been adopted by the IPCC) that consider "radiative forcing"[10] rather than being linked to socioeconomics and technological development.

[10] Radiative forcing is the ability of a gas, for example, to affect energy balance and so contribute to global warming.

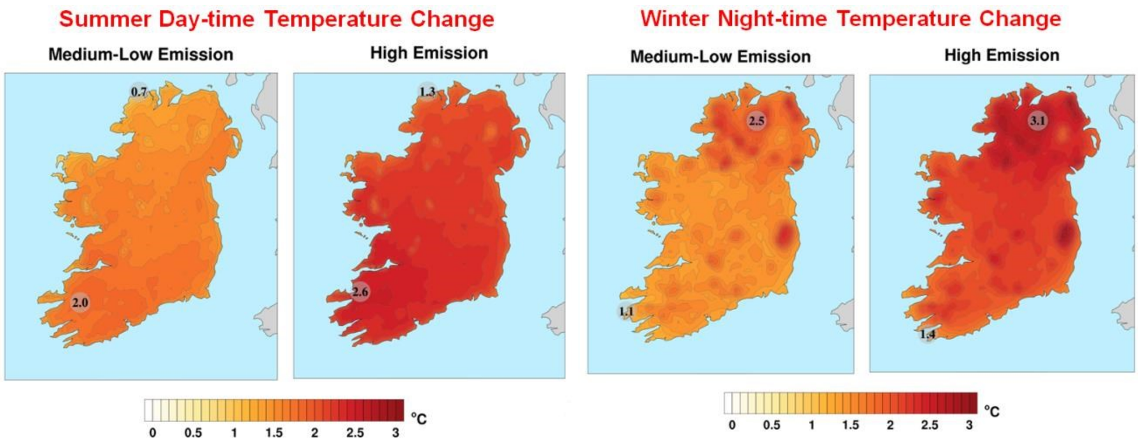
A1.1.1 Temperature

The average annual temperature on the IOI has risen by 0.7°C over the past century. Temperature distribution has changed as well, with differences in the warming rate between maximum and minimum temperatures (Fitzgerald et. al, 2009). These changes are expected to continue with temperatures projected to warm by 0.25°C per decade. Nolan (2015) used an ensemble approach to project that, by the middle of the century and assuming low to medium GHG emissions, the mean temperatures over the IOI will have increased by 1 to 1.5°C in the summer and by 0.5 to 1.5°C in the winter.

Climate change will also have an impact on extremes of temperature. Beniston et al. (2007) projects that the intensity of extreme temperatures increases will grow more quickly than the more moderate temperatures, especially over continental Europe. Changes in the extremes of temperature are more likely to have an important effect on lives and livelihoods than changes in the mean temperature (Easterling and Wehner, 2009).

Nolan (2015) predicts that winter nights will be warmer for the IOI. Projections indicate that the lowest 5% of night-time temperatures for the low to medium GHG emission scenarios show a higher increase in temperature in the northern part of the island (2.5°C) compared with the south (1.1°C). The highest 5% of summer daytime temperatures are also projected to increase (Figure A.1), with the southern part of the island warming more than the north. In a low to medium GHG emissions scenario this increase ranges from 0.7°C to 2°C.

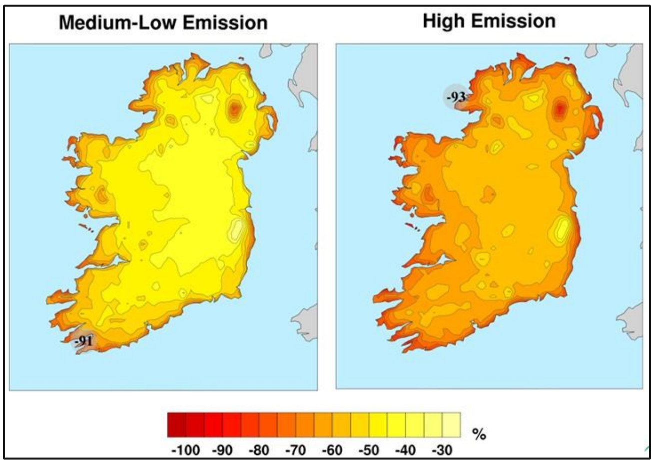
Figure A.1: Projected summer daytime (highest 5%) and winter night-time (lowest 5%) average temperature changes in 2041 to 2060 compared with 1981 to 2000 averages



Source: Nolan, 2015.

The numbers of frost and ice days are projected to decrease significantly by the middle of the century. Frost days, where the minimum temperature is below 0°C, are projected to decrease by 50% for low to medium GHG emission scenarios and by 62% for high emission scenarios. Figure A.2 shows that the western parts and coastal areas of the IOI will experience the greatest reduction. The number of ice days, where the maximum temperature is below 0°C, is projected to decrease by 73% and 82% for low to medium GHG emission and high emission scenarios, respectively.

Figure A.2: Projected change in the number of frost days between 2041 and 2060 compared with the period between 1982 and 2000



Source: Nolan, 2015.

A1.1.2 Precipitation

Currently, precipitation on the IOI varies greatly in quantity, frequency and distribution. The western half of the IOI generally averages between 1,000 and 1,250mm of rainfall per year and the east experiences between 750 and 1,000mm. Mountainous areas are an exception to this generalisation, with rainfall exceeding 2,000mm in some locations.

On average, April is the driest month for most parts of the IOI. The exception is the southern part where June is the driest month. The wettest months are generally December and January. Measurements have indicated a small increase (approximately 60mm) in rainfall when comparing averages from 1981 to 2010 with those from 1961 to 1990 (Walsh and Dwyer, 2012). However, the confidence level associated with this projected increase in rainfall is not as high as that for projected changes in temperature.

Numerous studies have used the IPCC emissions scenarios to project future changes in precipitation. Unlike temperature projections, there is a large disparity in the magnitude and direction of predicted precipitation changes. Nolan (2015) found that the future period (2041 to 2060) is projected to have 0 to 10% less annual precipitation than between 1981 and 2000 under low to medium GHG emission scenarios compared with 1 to 8% less under the high emission scenarios. This reduction is not equal over the seasons, with summer projected to experience higher reductions in rainfall. Mean precipitation in winter is also expected to decline, albeit with a low level of confidence.

Heavy rainfall events are projected to increase by around 20% during the winter and autumn months. “Heavy rainfall” is defined as days that experience precipitation greater than 20mm. Extreme storms are predicted to track further south by mid-century (Nolan, 2015). The rarity of extreme storms means that these predictions are not conclusive. Nolan (2015) predicts that the overall number of cyclones will decrease by around 10%. This is due to the projected decrease in mean sea level pressure.

At the other end of the spectrum, the number of drought events are expected to increase. Nolan (2015) used the projected change in the number of dry periods (defined as five consecutive days with less than 1mm of precipitation) to look at the effect of climate change on drought events. Dry periods are projected to increase by 7 to 28% by mid-century. The summer projections for dry periods show a “likely” increase ranging from 12 to 40%.

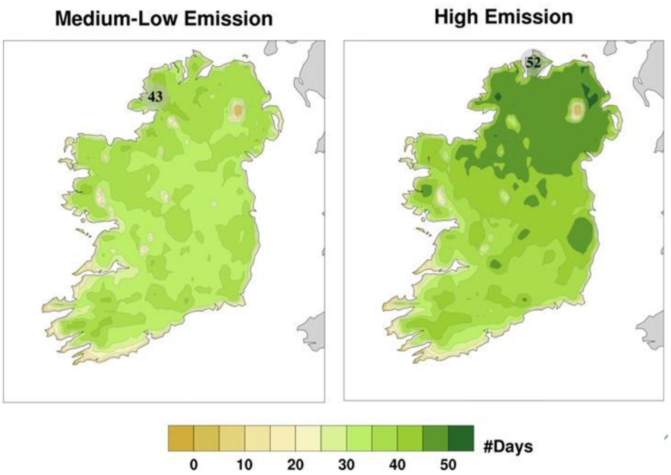
A1.1.3 Climate change and agriculture on the island of Ireland

Given the amount of changes that are expected to occur due to climate change on the IOI, it is obvious that agriculture will be affected. Temperature, precipitation and extreme weather events all have an impact on agriculture and the dairy sector. Air and soil temperatures are determinants in the level of agricultural production. They contribute in many different ways, through both grass and crop growth and the effect temperature has on livestock. The mean temperature is expected to rise marginally. However, the extremes are expected to rise to a greater extent.

The predicted warmer average temperature is positive for grass growth. The higher levels of CO_2 are expected to lead to higher growth also. The changes in extremes are likely to have the most significant effect on agriculture on the IOI and particularly in the dairy sector, which is a heavily grass-based production system. Changes in average temperatures over time may lead to ecosystem changes facilitating an increased prevalence of pests and diseases that thrive in warmer temperatures. It may also lead to a change in the make-up of pasture, as some grass types or weeds may benefit from the warmer conditions. Livestock can suffer from heat stress if temperature and humidity are high. They will also be susceptible to the increases in both the number and diversity of pests and diseases that could occur.

The reduced number of frost and ice days are likely to have a significant impact on the growing season, lengthening it at both ends. The thermal growing season length is defined as the number of days between the first occurrence of at least six consecutive days with a daily mean temperature above 5°C, and the first occurrence of at least six consecutive days with a daily mean temperature below 5°C. Nolan (2015) projects that, on average across the IOI, the growing season will increase by 35 or 40 days based on low to medium GHG emission or high emission scenarios, respectively. In both emissions scenarios, NI will experience the greatest change, as shown in Figure A.3.

Figure A.3: Change in length of the growing season by mid-21st century compared with current average



Source: Nolan, 2015.

The length of the growing season may be constrained by the availability of water. Projections suggest that precipitation will decline due to climate change. This is highly likely to occur in the summer months. An earlier start to the growing season may lead to the soils not having enough moisture to continue to promote grass growth at the other end of the growing season. As the number of dry periods is expected to increase, farmers may have issues with ensuring feed and water access over the summer months without purchasing inputs and so increasing costs.

Heavy rainfall events are expected to increase by around 20%, which could lead to flooding and waterlogged pastures, negatively affecting production. Storms are also predicted to track further south, which is where the majority of the dairy farms on the IOI are located. Storms and heavy rain could cause damage to farm infrastructure and livestock. These conditions may also affect access to farms that is required for both the supply of inputs and the extraction of raw milk to processors.

Given the importance of a favourable climate for agricultural production, there are innumerable risks associated with climate change. The unpredictability of the climate means it is not feasible to be prepared for all possibilities. Projections suggest that climate change will lead to a more volatile climate with the extremes changing much more than the averages. Also, both heavy rainfall events, which could lead to flooding, and droughts are likely to increase in prevalence and severity. It is important to identify the events that could impact the dairy supply chain to enable the development of adaptations that address vulnerabilities and improve resilience. This risk assessment is carried out in Appendix 3 in the form of a climate change risk identification exercise.

Appendix 2: Dairy supply chain

The supply chain as defined by Mentzer et al. (2001) is the set of entities directly involved in the upstream and downstream flows of products, services, finances or information from the source to the consumer. Within the agricultural sector, a supply chain can be defined as everything from "farm to fork". Mapping the dairy supply chain requires identifying each of the actors within the chain and their contributions.

The term "supply chain" is often used interchangeably with concepts such as "commodity chain", "sub-sector" and "value chain" (Jaffee et al., 2010). Originally the term "supply chain" related to the logistics and delivery of goods and services only. It has expanded to include the entire process. The term "value chain" is often used when discussing possible ways to add value at each stage of the chain or create a more equal distribution of value added across the chain.

Supply chain management (SCM) is used to improve supply chains. In the food industry, this involves improving food safety, ensuring security of supply and minimising material and financial waste. For the purposes of this study, a simplified version of the supply chain is used due to the complexity of the entire system. The stages, products and services and actors in the supply chain are adapted from Heery et al. (2016), Le Heron (2010) and Jaffee et al. (2010). The stages are

- Inputs
- Production
- Primary and secondary processing
- Marketing and distribution
- Retail.

A detailed description of each stage of the supply chain is provided here.

A2.1 Inputs

The production and distribution of material inputs to farms is the first stage in the dairy supply chain. Inputs to dairy production come in two main groups:

1. Pasture-related inputs. These include land, infrastructure (e.g. buildings and farm machinery, fuel and fertilisers.
2. Animal-related inputs. These include stock, feed, electricity and veterinary services.

Actors include equipment vendors, fertiliser and feed suppliers and veterinarians.

The costs for these inputs are split into two categories:

1. Direct costs, which vary with output
2. Overhead costs, which are incurred with or without production.

Feed, fertiliser and energy (fuel and electricity) are three of the most important inputs in the production of milk. Other costs include labour, veterinary expenses, artificial insemination (fertilisation of livestock) and machinery hire and purchase. Figure A.4 shows the breakdown of costs and relative use of inputs for dairy farms in both the ROI and NI in 2014.

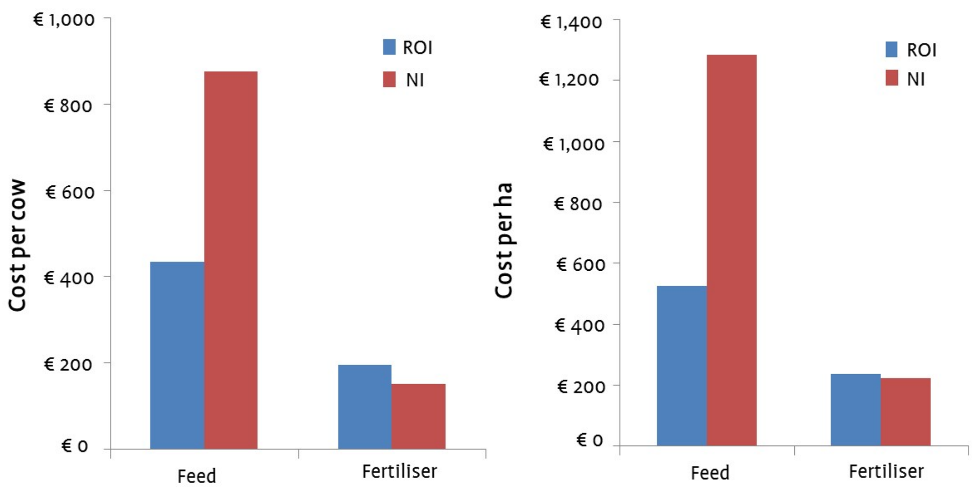
The primary financial input in milk production is concentrate feed (e.g. seeds and grain) and fodder (plant-based feedstuff), which account for 24% of costs in the ROI and nearly 38% in NI. Fertiliser is the second most important input, representing 11% of costs to dairy farmers in the ROI and 7% in NI. Livestock inputs, including veterinary fees and artificial insemination, account for 8% of costs for both jurisdictions (Hennessy and Moran, 2015; DARD, 2015).

Figure A.4: Input expenditure of dairy farms in the ROI and NI in 2014

Source: Hennessy and Moran, 2015 and DAERA, 2015.

The dairy sector in the ROI is characterised by low-input, grass-based production with dairy herds on pasture for up to 300 days per year. This is complemented principally by dry matter intake of hay or silage and, to a smaller extent, compound feeds. The average dairy cow was fed 949kg of concentrates in 2014 and spent 244 days on grass (Hennessy and Moran, 2015). See Figure A.5 for data on the relative importance of feed and fertiliser as inputs to dairy production in the ROI and NI.

Figure A.5: Feed and fertiliser costs per cow and per hectare in the ROI and NI (Euro equivalents) in 2014



Source: Hennessy and Moran, 2015 and DARD, 2015.

In comparison with the ROI, production systems in NI are somewhat less reliant on grass and use more purchased animal feed. This means that farmers in NI are more exposed to animal feed price volatility. Farmers in the ROI are more exposed to local weather conditions (grass growth variability) and movements in fertiliser prices.

A2.1.1 Feed

Purchased feed consists mostly of cereal concentrates based largely on barley and wheat that are used to improve nutrition, and compound feeds that are a blend of raw materials and additives. The ROI produces just over 2.5 million tonnes of cereals, mostly barley. Up to 65% of animal feed requirements in the ROI are imported. This is a much higher share than that of other EU countries such as the UK

(37%), France (27%) and Germany (26%) (DAFM, 2015b). Similarly, NI is also heavily dependent on feed sourced from beyond the IOI. The EU does not produce enough protein for animal feed internally. Imports into the IOI are sourced from further afield including the USA, Argentina, Brazil and Canada. The main European suppliers of animal feed to the IOI are France, the UK, the Netherlands and Germany.

A2.1.2 Fertiliser

Fertiliser is used to maintain soil fertility and promote grass growth. All of the fertiliser used in the IOI is imported. The vast majority comes from Great Britain or Belgium and a significant amount is also imported from Russia.

The price of fertiliser is dependent on the price of its compounds, mainly nitrogen, phosphorus and potassium. Obtaining these compounds is the most energy-intensive part of fertiliser production.

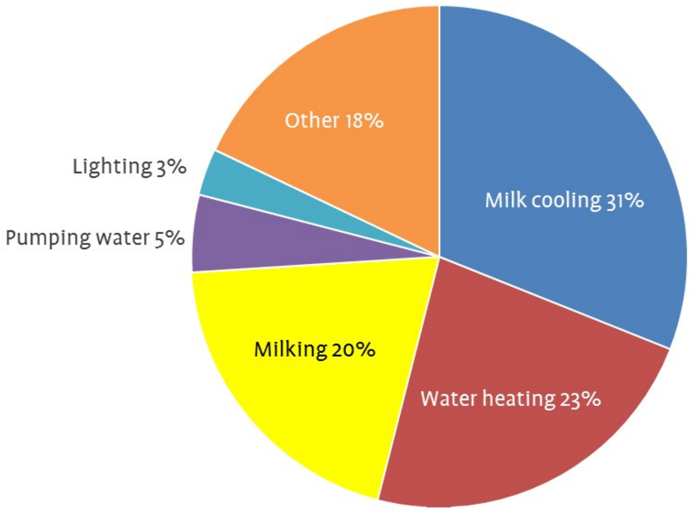
Natural gas is used for over 70% of nitrogen production whereby ammonia is an intermediate product.The current main source of phosphorous is phosphorous rock. This is generally obtained from open cast mines. Due to the non-renewable nature of the rock there are concerns that “peak extraction” – the maximum rate of phosporous production possible globally – will soon be reached. Price increases could be inevitable as the supply dwindles.

Potassium is obtained from mining potash (potassium-rich salts). The current driver of both phosphorus and potassium prices is the cost of the energy that is needed for extraction and transport.

A2.1.3 Energy

The two major energy uses on dairy farms on the IOI are electricity and fuel. Energy is required for many of the activities that take place on a dairy farm. These include maintaining pastures, milking cows, cooling milk and harvesting fodder crops. A study of 22 farms in the ROI by Upton et al. (2013) found that almost 80% of the total electricity used was in the milking shed. Milk cooling, water heating and milking are the main users of electricity as can be seen in Figure A.6.

Figure A.6: Breakdown of the electricity usage of 22 farms in the ROI in 2011



Source: Upton et al., 2013.

Fuel is mainly used for machinery and on-farm vehicles. Oil prices and taxation rates are the main drivers of fuel prices in the ROI and NI. Within the dairy supply chain, fuel is used on site and to transport other inputs to the farm. It is also used to transport milk output to the processer and onwards through the supply chain. The price of energy inputs and outputs will directly and indirectly affect farm costs.

A2.1.4 Other inputs

There are a number of other inputs to farms in the dairy sector, such as veterinary and artificial insemination inputs that are required to ensure a healthy and fertile herd. Machinery and specialised equipment are also important inputs required for the milking process, silage making, maintaining pastures and growing crops. Machinery is either owned, hired or borrowed and requires either fuel or electricity to run. Water is also an important input to the milk production process. Murphy and co-workers (2014) found that around 6.4 litres of water is used on ROI dairy farms for every litre of milk produced. As most of the present water supply is obtained from surface water, with up to 25% coming from groundwater, rainfall is extremely important.

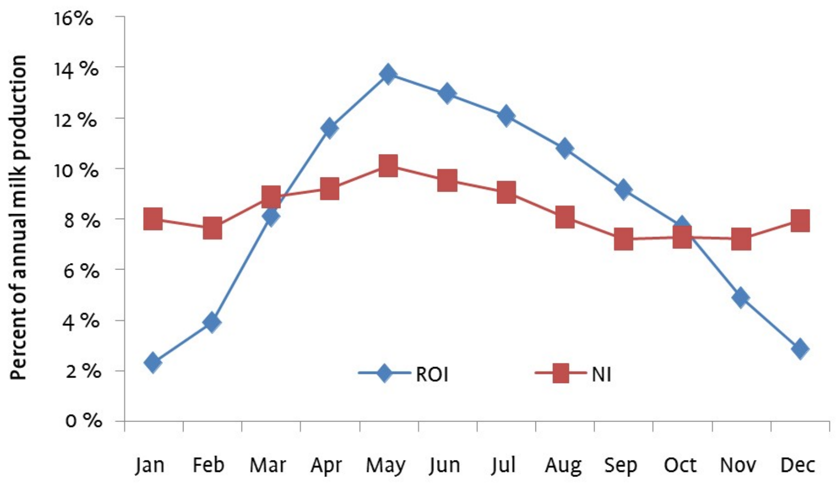
A2.1.5 Production

The production stage of the dairy supply chain consists of primary agricultural production, also known as the farm sector. The end point of this stage is the sale of the raw commodity – milk – at the farm gate. On the IOI, the actors at this stage of the supply chain are a large number of commercial dairy farmers of moderate scale.

Milk produced on the farm is mostly sold to processors. A small amount is fed to calves or used for on-farm consumption. Milk production in NI totalled 2,266 million litres in 2015 and was produced on 2,655 farms (DAERA, 2016). This was valued at £479.9 million at the farm gate. The ROI produced 6,395 million litres in 2015 from 15,588 farms (CSO, 2016). The size of the average dairy herd differs between the two jurisdictions with an average of 70 cows per farm in the ROI and over 100 cows per farm in NI (Hennessy and Moran, 2015; DARD, 2015).

Production in the ROI is highly seasonal due to the pasture-based system. In NI seasonality is less distinct (Figure A.7). This is because suppliers were given incentives to encourage the provision of a consistent supply of milk throughout the year, which led to a higher use of concentrates for feed.

Figure A.7: Average distribution of milk production by month between 2010 and 2015

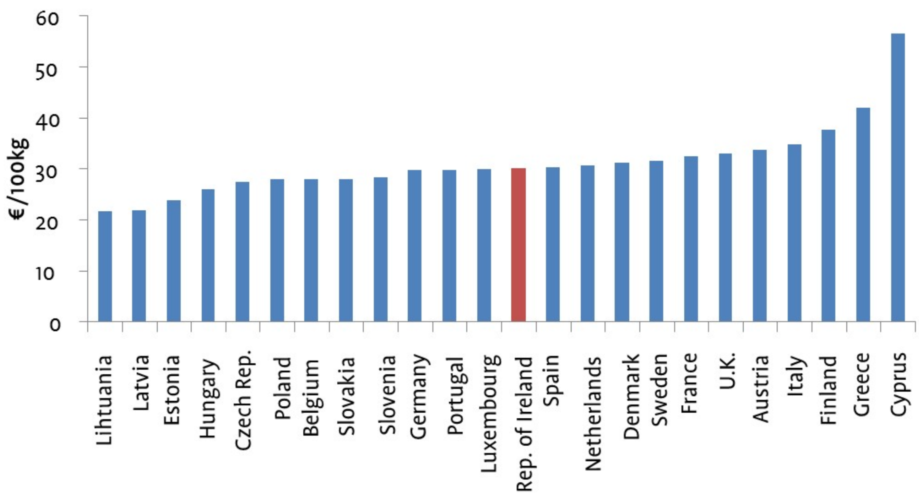


Source: CSO, 2016 and DAERA, 2016.

The price dairy farmers receive for raw milk is determined by the processor. The world market for dairy products and the supply of dairy products in other countries contributes to this value. In the ROI, farmers receive a price that ranks them approximately midway compared with other EU member states, as shown in Figure A.8.

In 2015, farmers in the ROI received around 30 per 100kg of raw milk, compared with 38 in the other major European producers of milk – the Netherlands, Denmark and Finland. Milk prices in NI are generally a little higher than those in Great Britain. UK prices are generally lower than prices in the ROI, except in periods of international market weakness.

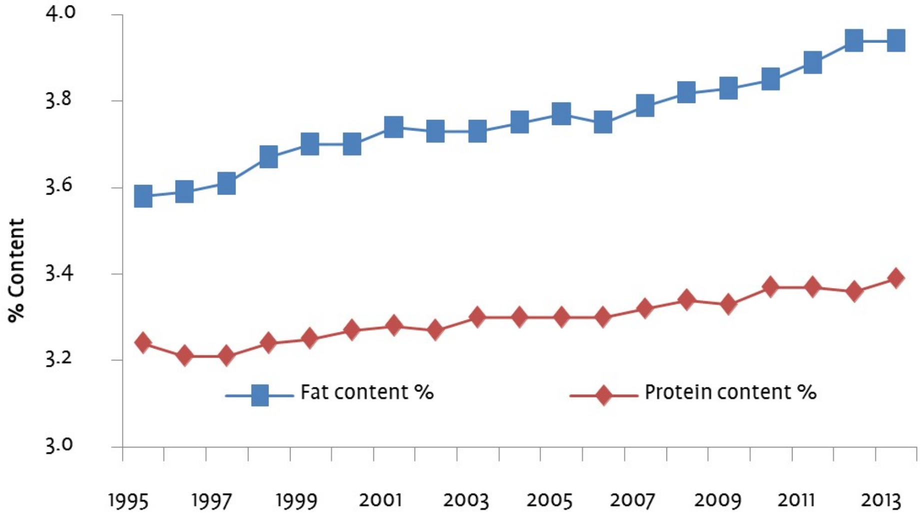
Figure A.8: Average raw milk price per 100kg in Europe in 2015



Source: Eurostat, 2015.

Dairy farmers are paid for their milk by processors based on the amount of fat and protein in the milk. Protein is worth around twice as much as fat. Most co-operatives in the ROI pay for milk on an "A+B-C" basis, where "A" is the price paid for protein, "B" is the price paid for fat and "C" is the cost of processing. The level of fat and protein in milk has been increasing over the years in the ROI, as shown in Figure A.9. This has been attributed to improvements in breeding and feeding as well as the farm payment method for milk.

Figure A.9: Fat and protein content of milk produced in the ROI between 1995 and 2013

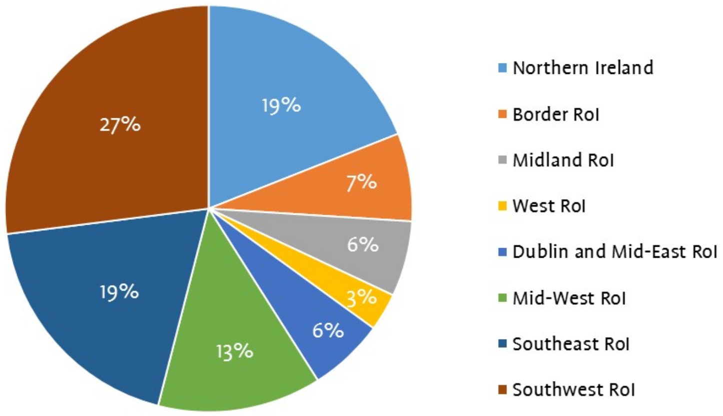


Source: Eurostat.

A2.1.6 Location

Dairy farms need appropriate soil, precipitation and temperatures, among other factors, to be productive and profitable. As a result, dairy farms on the IOI are highly concentrated in the southern part where the conditions are more favourable for intensive farming. The southeast and southwest of the IOI stocked 46% of the island's dairy cows in 2015, as shown in Figure A.10. In the same year, NI had 19% of the total number of dairy cows on the island.

Figure A.10: Share of dairy cow stocks on the IOI by region in 2015



Source: CSO, 2016 and DAERA, 2016.

A2.1.7 Processing

The processing stage involves the transformation of raw materials into one or more finished goods. The main actors at this stage of the dairy supply chain are milk processing companies. The processing industry in the ROI is made up of 16 processors. These range from smaller co-operatives, such as North Cork, to large globally operating co-operatives, for example Dairygold. There are also some public limited companies (PLCs) such as Glanbia and Kerry Group but these companies have retained a co-operative structure for their milk processing divisions in the ROI.

Six co-operatives processed 82% of the ROI's milk in 2013 (DAFM, 2014). In addition to these, there are a number of multinational corporations that conduct secondary processing of dairy products creating goods such as infant formula (Abbott, Danone, Wyeth and Kerry Group) and chocolate crumb (Mondelez). As of 2013, there were 12 main processing companies operating in NI with eight of these processing 80% of milk (Agri-food Strategy Board, 2013). NI also exports a substantial proportion of raw milk to the ROI for processing. In 2015, 26% of the total raw milk produced in NI was exported to the ROI (National Milk Agency [NMA], 2016).

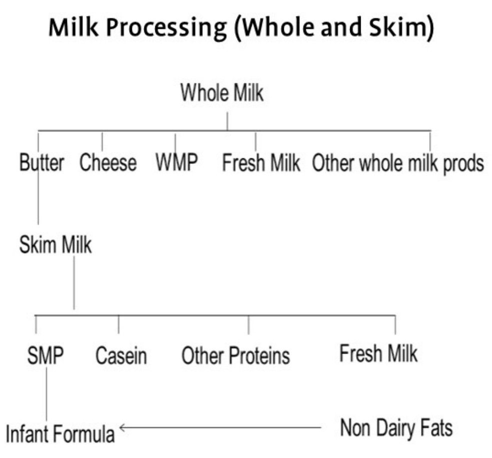
Co-operatives are owned by the farmers, who retain key decision making roles. This form of vertical integration into the supply chain – where a company combines two or more stages of production that are more often undertaken by separate firms – gives farmers more power. The farmers can get together and process their milk to create goods of higher value, enhance marketing power and maximise their returns. Co-operatives and their subsidiaries (also called "daughter companies"), in which the co-ops hold shares, were estimated to conduct 98% of primary milk processing and 98% of export marketing of dairy products in the ROI in 2007 (Forfás, 2007).

The number of processors in both the ROI and NI has declined significantly over the years through a process of consolidation or combining of businesses due to competitive pressures. However, the processing sector remains fragmented compared with other important export-orientated dairy producing countries such as New Zealand, Denmark and the Netherlands where there is only one dominant processor. The fragmentation of the dairy processing sector in the ROI has been identified as a weakness due to duplication of investment, small scales and relative inefficiencies in processing (Murphy, 2014).

The processing of dairy products involves processing liquid milk for human consumption and the separation of its different constituents for the manufacture of other dairy products such as butter, cheese and whey powder. This is done through the concentration and separation of milk solids including proteins, carbohydrates, organic acids and minerals. Some of the products obtained from the first stage of processing go on to secondary processing to create higher value products such as infant formula, sports nutrition products and confectionary. These products are made using either whole or skim milk, as can be seen in Figure A.11.

Figure A.11: Milk processing and product utilisation in the ROI

(A.11a)



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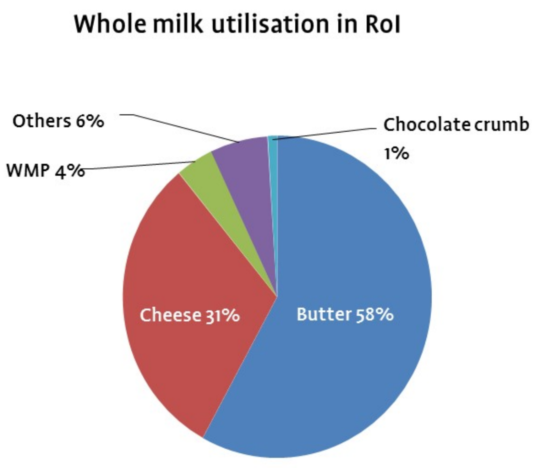
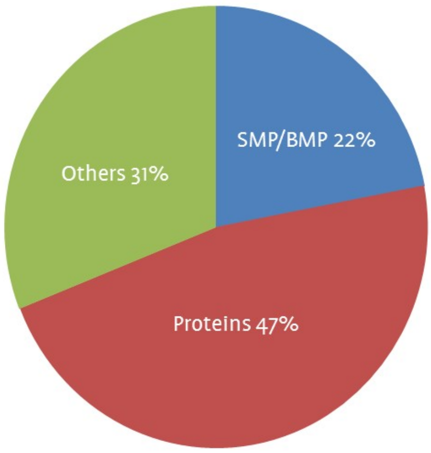


Source: Hennessy and Moran (2015).

Just 8% of the milk pool in the ROI is used for the liquid milk market. More than half of whole milk is used for butter production, as can be seen in Figure A.12. Over 30% is used for making cheese, with small amounts used for whole milk powder, chocolate crumb and other uses.

Skim milk is generally a by-product of the creation of cream or butter. Nearly half of skim milk is used for the production of proteins such as casein and caseinates. The remainder is split between skim milk powder and other skim milk products.

Figure A.12: Skim milk utilisation in Ireland in 2012



Source: Irish Dairy Board, 2013.

A2.1.8 Specialised products

Technological advances in processing have increased the range of goods processors can make, allowing them to branch into sectors that allow for higher profit. This also permits product differentiation through both the processing and marketing stages. The development of whey protein isolate and the large increase in demand for protein powders has allowed the processing sector to create profits from what used to be a minimally valued by-product of dairy production.

For example, infant formula has become an increasingly important export for the dairy sector in the ROI, contributing 37% of the sector's export value in 2015. Infant formula also has a higher mark-up than standard dairy commodities and so is more profitable for processors. Three of the world's top infant formula manufacturers have operations in the ROI: Abbott/Nestlé, Danone and Pfizer/Wyeth.

The Chinese infant formula market is growing rapidly and almost 40% of the ROI's infant formula was exported to China and Hong Kong in 2015.

Another example of value added is in whey-based products. Whey is a by-product of cheese and casein production that until recently had little value. However, due to advances in science and processing technology, whey is now used in many goods such as infant formula, snack foods and protein powders. Whey protein isolate with 90% protein can now be made from the base product. This is a valuable ingredient for the sports nutrition industry. This industry is estimated to be worth over US$10 billion globally and is still growing at around 11% per year (DAFM, 2015b). The expanding market for protein powders and other whey-using dairy products presents significant market opportunities for processors.

A2.1.9 Inputs to processing

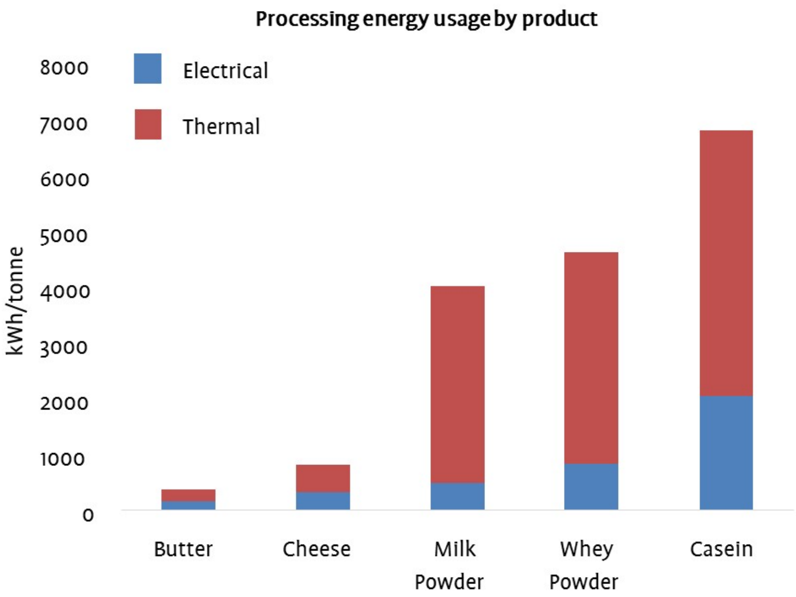
Processing milk for consumption requires energy. The energy used is either electrical or thermal (heat). The different end products require different amounts of each energy type as shown in Figure A.13.

Large quantities of water are used in processing dairy products. A reliable water source to provide constant cleaning is essential to production. Of the processing plants surveyed by Finnegan and co-workers (2015), the largest source of this water is surface water (58%) followed by groundwater (40%). Public supply accounted for just 2% of the water used. Plant sites are often located near a large water course for this reason and also because it allows for disposal of effluent from on-site wastewater treatment facilities.

The more basic products such as butter and cheese require only a small proportion of energy in comparison with the secondary processed goods such as milk powder and casein that require removal of the water content.

Approximately half of the energy requirements are sourced from on-site generation, primarily through CHP systems. The remainder is obtained from the National Power Grid. Thermal energy is mostly provided by three fuels: natural gas (69%), fuel oil (20%) and coal (8.7%) (Geraghty, 2011).

Figure A.13: Average energy used in dairy processing by product in the ROI



Source: Geraghty, 2011.

Geraghty (2011) conducted a study on the resource efficiency of dairy processing in the ROI with the co-operation of many of the companies in the sector. It was found that, due to investment in the area, energy use has been reducing significantly thereby also reducing the average CO_2 emissions of each processing plant. Water usage also declined by 200 million litres annually per plant on average between 2005 and 2009 – a reduction of 28%. Finnegan et al. (2015) found a further reduction of 9% occurred between 2009 and 2013, to 2.28 cubic metres of emissions per cubic metre of milk processed

A2.1.10 Marketing and distribution

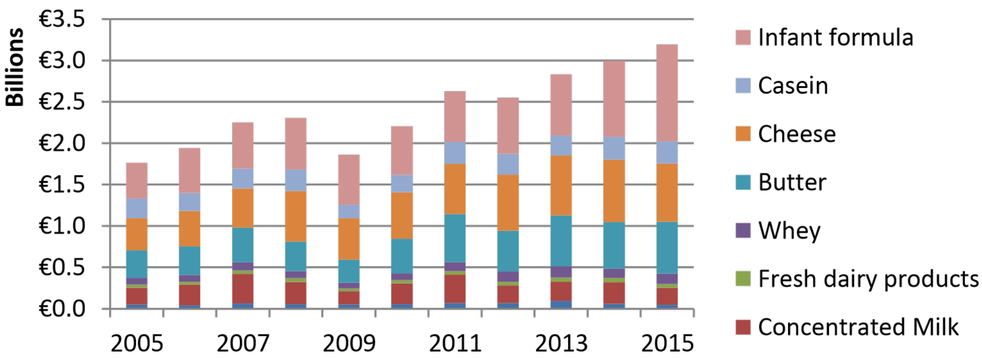
This stage of the supply chain involves bringing dairy products from the processing plants to the market. The main actors at this stage are dairy processing companies that are integrated across the supply chain, and export agencies. Marketing IOI dairy products and distributing the goods to retailers is an important step in the dairy supply chain.

Domestic consumption of the dairy products produced within the IOI represents only a small portion of the total. Europe is the primary destination for exports. However, the Asian market is growing. In the ROI, the marketing and distribution of dairy products on an international scale is conducted for the most part by the three largest processors (Glanbia, Dairygold and Kerry Group) and Ornua (previously known as the Irish Dairy Board). These actors have considerable control over the supply chain, from milk collection through to sales, often spanning more than one stage of the supply chain. Ornua is the largest dairy product exporter in the ROI.

Another actor that takes part in marketing dairy products is Bord Bia, a state agency that aims to promote sales of Irish food and horticulture both within the ROI and abroad. The National Dairy Council markets milk and other dairy products to consumers in the ROI by providing information about the health and nutrition benefits. The Northern Ireland Dairy Council performs a similar role in NI.

Dairy exports accounted for approximately 30% of the ROI's food and drink exports in 2015 (Bord Bia, 2016). The value and quantity of dairy exports reached 3.24 billion in 2015 – a 4% increase on 2014. This was largely due to an increase in volume caused by the removal of milk quotas. Butter, cheese and infant formula are the three main export earners from the ROI as shown in Figure A.14. The ROI exports dairy products to over 130 markets worldwide. The top five destinations are the UK, China, the Netherlands, Germany and the US (Bord Bia, 2016). The UK accounts for nearly a third of the ROI's dairy exports. NI exports over 80% of its dairy output (Agri-food Strategy Board, 2013). This was worth £795 million in 2014 including exports to the UK (DARD, 2015).

Figure A.14: Dairy product exports from the ROI between 2005 and 2015



Source: Eurostat Comext.

A2.1.11 Retail

Sale to the final consumer is the final step in the dairy supply chain. This includes sales to restaurants or caterers, or as ingredients to other food manufacturers. A relatively small proportion of the dairy products produced in both jurisdictions are consumed domestically.

A large portion of the retail activities within the IOI are undertaken by multinational supermarkets. They take part in marketing, distribution and the sale of the final product. This allows them to have a substantial amount of control over the supply chain especially in the case of liquid (drinking) milk, which is the most consumed dairy product in the IOI.

The sale of drinking milk in the ROI is primarily operated by a number of retailers who account for 79% of the distribution of fresh milk. The catering channel for milk distribution stands at 11%, while doorstep milk deliveries comprise 10% of fresh milk distribution and sales in the country (NMA, 2016).

Supervalu is currently the most popular grocery retailer in the ROI, commanding 22.4% of the grocery market share as of September 2016. Dunnes Stores and Tesco occupy 21.6% each of the market (Kantar Worldpanel, 2016). These three retailers dominate the grocery retailer sector in the ROI, comprising over 65% of the sector. German discount retailers Lidl and Aldi constitute a share of 11.7% and 11.4% respectively, taking up fourth and fifth positions.

In NI, Tesco has a commanding lead over other grocery retailers, occupying 34.8% of the grocery market share in September 2016. Sainsbury's and Asda are in joint second position, each with 17.6% of the market share (Kantar Worldpanel, 2016). Lidl saw an increase in its sales up to September 2016, resulting in a 5.2% share in the grocery market in NI. Aldi does not operate in NI.

The ROI's most popular grocery retailer, Supervalu, stocks only National Dairy Council (NDC) approved milk in its premium brands and in its own brand milk. The NDC logo, or accreditation, tells the consumer that the milk they are purchasing was produced and processed in the ROI. Seven creameries across the ROI supply Supervalu with milk for its own brand range (NDC, 2014), and sales of its own brand milk average at 736,000 litres per week.

Tesco stores in the ROI only stock NDC approved milk. Its own brand milk range is supplied through three large Irish dairies: Glanbia, Arrabawn and Aurivo, with Tesco's own brand butter and cream entirely supplied by Glanbia. In 2015, Lakeland Dairies in Cavan won a contract to supply Tesco Ireland with a premium own brand ice cream range. Lakeland Dairies has been supplying Tesco since 2012. Including the new ice cream range, sales of over 1 million are forecast over the next year for Lakeland Dairies in Tesco stores in milk, butter and ice cream products (Tesco Ireland, 2015).

Although Dunnes Stores stocks NDC-accredited branded milk, its own brand milk does not carry the NDC logo. This indicates that the milk it uses for its own brand milk range is produced in NI (Irish Independent, 2012). The export of milk from NI to the ROI has steadily increased over the past decade. In 2015, 25% of the liquid milk consumed in the ROI, or one in every four litres, was produced in NI.

A2.1.12 Transportation

Transportation is required throughout the dairy supply chain to move goods to the next stage. This includes getting inputs to the farm and transportation of milk from the farm to processing facilities.

Finally, the products are transported to their sale destination within the IOI or internationally. Transportation is highly reliant on infrastructure. Without reliable road access between farms and processors both will face financial consequences. Milk is a perishable commodity so time is important. Road closures may result in the spoilage and therefore wastage of milk.

Milk is generally transported from farms to the processor in milk tankers. A survey found the weighted average milk transport cost in the ROI to be 1.15 cent per litre (Quinlan et al., 2005). Many factors influence the cost of transport at this stage of the supply chain. They include the distance between farms and processing plants, truck and tanker size, frequency of collection, seasonality of milk production, labour costs, route management, fuel costs and interest rates, among other things (Quinlan et al., 2010).

As the number of processors declines, the cost of transportation between the farm and the processor is increasing. Transportation of raw milk in the ROI could be cheaper if milk supply was less seasonal (Quinlan et al., 2005). There is also an overlap in catchment areas from which the current milk processors source their milk. Reorganisation of this could lead to cost reductions.

A2.1.13 Milk Imports

Ireland imports bulk milk from NI. Following the trend of increasing milk and dairy product sales, importation of bulk milk has grown year on year from 2011, reaching 594 million litres in 2015 – the highest figure on record. 90% of this bulk milk imported (532 million litres) is designated for processing into manufactured dairy products in the ROI. The remaining 10% (62 million litres) is earmarked for processing for liquid consumption (NMA, 2016). The scrapping of the milk quotas in April 2015 encouraged dairy producers in NI to increase their milk output. In 2015, NI exported almost 600 million litres of bulk milk to the ROI (CSO, 2016).

Imports of processed and packaged milk from NI, which is consumer ready, have also increased over the past decade. The NMA estimates that 94 million litres of fresh milk in consumer packs were imported into the ROI from NI in 2015. This represents an increase of 1 million litres on 2014, and a 50% increase in the volume imported in 2006. The total milk imports from NI by processors and pasteurisers amounted to 688 million litres in 2015 and were equivalent to 11% and 30% of the ROI's and NI's annual milk supply, respectively (NMA, 2016).

Appendix 3: Climate change risk identification of the island of Ireland dairy production sector

Conducting a risk assessment for the dairy supply chain in relation to climate change requires an analysis of the possible risks and their effects. Mapping the supply chain was a significant step in conducting this assessment as it is important to recognise the actors involved, what they contribute and the inputs required at each step. Using this information, climate change risks to the dairy supply chain can be identified. The risks are identified through an examination of relevant literature with regard to both the dairy sector and other fields. Where possible, the predicted effects of these risks for the IOI are presented. However, some research is yet to be conducted in certain fields.

A risk assessment is conducted using the Rapid Agricultural Supply Chain Risk Assessment (RapAgRisk) framework (Jaffee et al., 2010). This framework helps to identify factors that could weaken competitiveness, sustainability and other performance results within agricultural supply chains. It also aids in identifying the categories of risk that agriculture faces and defining what is included in each category. This allows a methodical approach in identifying the risks.

A3.1 Definition of risk

Risk can be defined in multiple ways depending on the circumstances. Spekman and Davis (2004) define it as the probability of variance in an expected outcome. It is also argued that risk occurs when the probability of outcomes is not known for certain – in other words, when there is uncertainty (Yates and Stone, 1992). If this definition is used, then climate change and the uncertainty surrounding it causes risk for anything reliant on the climate.

Juttner et al. (2003) defined risk in relation to a supply chain as anything that presents a threat to information, material and product flows from the original supplier to the end user. Climate is naturally unpredictable. Therefore, even without the effects of climate change some risk is present.

Climate change is expected to lead to changes in temperature and precipitation, among other factors. The increased possibility of extreme weather events also means that the climate will become less predictable. By Yates and Stone's (1992) definition, this means that risk is increasing. This study will only look at the increased risk due to climate change.

A3.2 Methodology

The objective of supply chains is profit maximisation (Nelson and Toledano, 1979). Each step of the supply chain must be carefully managed to add maximum value. The concept of SCM first appeared in the mid-1980s (Houlihan, 1985). Cooper et al. (1997) defined it as the integration of business processes from end user through original suppliers that provides products, services and information that add value for consumers. An effective and efficient supply chain is resilient to both internal and external risks.

Supply chain risk management is a smaller area of research within the larger scope of SCM that attempts to identify and propose solutions to risks. Jaffee et al. (2010) define it as the systematic process of managing damaging events that can negatively affect the supply chain. This requires coordination or collaboration among the supply chain partners to ensure profitability and continuity (Tang, 2006). Risks must be identified both within the supply chain and externally to be able to reduce vulnerability through management.

Supply chain risk assessments are used to identify the sources of risk to a supply chain. These assessments use the categories and definitions of risks identified in RapAgRisk as developed by the Agricultural Risk Management Team of the World Bank (Jaffee et al., 2010). This methodology was chosen because of its focus on agriculture.

Many other supply chain risk assessments look at the risks to manufacturing supply lines. The drawback to using such approaches is that they often look at operational risks rather than disruption risks, which climate change will likely cause (Colicchia and Strozzi, 2012). This leads to an emphasis on the production stage of the supply chain, which is comparable to the processing stage in the dairy sector where the climate does not have the greatest impact.

Climate change impact assessments often run scenarios, such as those conducted to predict the future levels of precipitation and temperature, to assess the impact of climate change on a particular topic (Jones, 2001). The level of information required to do this for the entire dairy supply chain makes this impractical. The RapAgRisk methodology overcomes these problems, as it is specific to agriculture and can be altered to look at climate change as the only source of risk, which has been done for this assessment.

The categories used in RapAgRisk are weather-related risks, natural disasters, biological and environmental risks, market-related risks, logistical and infrastructural risks, management and operational risks, public policy and institutional risks and political risks. The definitions of each risk category as defined by Jaffee et al. (2010) are included in Table A.1.

The majority of the risks identified are farm-based. A dairy farm is highly influenced by the climate, especially on the IOI where the dairy industry is highly reliant on grass for production. The effects on the farm are felt throughout the supply chain. It determines the level of inputs needed, as well as the level of production and quality of milk available to process and sell to consumers.

For each category, the risk is identified along with what its impact could be and why it is important. The risks were identified through a study of the literature that already exists on the topic. Some of the categories have been omitted. These include managerial and operational, logistical and infrastructural and political risks. This is because the risks found within these categories were secondary risks caused by other identified risks, or else they were not relevant to climate change. For example, although political risk such as the interruption of trade due to disputes between countries is a significant risk to agriculture and the dairy sector on the IOI these risks will not likely be aggravated by climate change.

The list of risks in Table A.1 is not all-inclusive as there are innumerable possible risks of varying degrees of severity that could occur throughout the supply chain. However, the risks presented are those that have been identified as being the most important, through a study of the current literature.

Table A.1: Categories of major risks facing agricultural supply chains

Type of risk	Examples
Weather-related risks	Periodic lack of or excess rainfall Extreme increases or decreases in temperature Hailstorms Strong winds
Natural disasters (including extreme weather events)	Major floods and droughts Hurricanes, cyclones and typhoons Earthquakes Volcanic activity
Biological and environmental risks	Crop and livestock pests and diseases Contamination related to poor sanitation, human contamination and illnesses Contamination affecting food safety Contamination and degradation of natural resources and environment Contamination and degradation of production processes and processing systems
Market-related risks	Changes in supply or demand that impact domestic or international prices of inputs or outputs Changes in market demands for quantity or quality attributes of products Changes in food safety requirements Changes in market demands for timing of product delivery Changes in enterprise or supply chain's reputation and reliability
Logistical and infrastructural risks	Changes in transport, communication and energy costs Degraded or unreliable transport, communication or energy infrastructure Physical destruction Conflicts Labour disputes affecting transport, communications and energy infrastructure and services.

Management and operational risks	Poor management decisions in asset location and livelihood or enterprise selection Poor decision making in use of inputs Poor quality control Forecast and planning errors Breakdowns in farm or firm equipment Use of outdated seeds Not being prepared to change product, process or markets Inability to adapt to changes in cash and labour flows, and so on
Public policy and institutional risks	Changing or uncertain monetary, fiscal (governmental finance) and tax policies Changing or uncertain financial (credit, savings and insurance) policies Changing or uncertain regulatory and legal policies and their enforcement Changing or uncertain trade and market policies Changing or uncertain land policies and tenure (land occupation) system Governance-related uncertainty (e.g. corruption) Weak institutional capacity to implement regulation
Political risks	Security-related risks and uncertainty (e.g. threats to property or life) associated with politico-social instability in a country or in neighbouring countries Interruption of trade because of disputes with other countries Nationalisation or confiscation of assets, especially for foreign investors

Source: Jaffee et al., 2010

A3.3 Weather-related risks

Non-extreme weather events arising from climate change pose risks to the dairy supply chain. These are likely to affect the chain for a single production cycle. The cause of these risks include too much or too little rainfall, or too high or low temperatures, within a short time period. Weather is highly important for dairy production. It determines the length and success of the growing season and the productivity of dairy cows. Non-extreme weather risks are likely to affect only specific geographic locations at one time. The two risks detailed here are

1. Changes in grass and fodder crop production
2. Heat stress.

A3.3.1 Changes in grass and fodder crop production

Predicting grass and fodder crop growth on the IOI is difficult due to the uncertain availability of water in the future. Grass production is expected to be positively affected by both the increase in temperature and CO_2 quantities in the soil. Grass growth will also be aided by the expected increase in growing days and the reduction in frost days. However, the increased growth in winter could use up soil moisture at the expense of spring growth (Sejian et al., 2015). In addition, the expected increase in dry periods over summer, especially in the dairy-intensive southern part of the IOI, means that there may not be enough water.

Holden and Brereton (2002) predicted that grass production on the IOI would decrease in the east of the island and may need irrigation to remain viable. The west of the island would see increased grass growth. However, the model used for this study did not include CO_2 fertilisation levels in the soil. With CO_2 levels included, Fitzgerald et al. (2009) estimated that grass growth could increase by 17% annually. The highest increases in productivity on well-drained soils were predicted to be in the northeast part of the IOI. On poorly drained soils, the greatest increases are predicted to occur in the central to northern parts of the IOI.

An example of the effect a bad growing season could have on IOI farmers was seen in 2012 and 2013. The growing season in 2012 was poor, followed by a long winter into 2013. This affected both grass and other fodder crop production, leading to a shortage of fodder on many farms and increasing the dependency on external feed (Donnellan et al., 2013). Internationally, there was a poor harvest so feed prices were high. This led to financial difficulties for many farmers. The government intervened by partially subsidising the importation of fodder from the UK and France to help with the cost. The 2013 Teagasc National Farm Survey showed that expenditure on concentrate feed increased by 34% on ROI dairy farms in 2012 (Hanrahan et al., 2013).

The uncertainty surrounding climate change impacts on grass growth poses a major risk to the dairy supply chain. The IOI dairy industry is predominantly grass-based. Changes in the ability to graze cattle on grass will have a significant impact on income for dairy farms. If grass and fodder crop levels do not cover the livestock nutrition needs of farmers they will need to purchase more from suppliers. Climate change may present an opportunity to farmers if the growing season is longer and more grass grows due to the temperature and CO_2 levels in the soil. However, the key unknown variable element, apart from the extent of climate change, is the availability of water. Current predictions suggest that precipitation will decrease. This is especially likely in summer, with increases projected in the frequency of dry periods.

Changes in grass production could result in either an opportunity for or a threat to the dairy supply chain. An increase in grass production would result in higher milk output. The demand for purchased feed would likely decline, as it would be an expense that could be minimised; this would then have an impact on feed suppliers. The increase in production may require processors to expand their facilities to be able to cater for the quantity of milk long term.

The global increase in demand that is expected will mean that finding markets for the increased quantity of dairy produce should not be too difficult. However, those conducting marketing and distribution may have to compete with other countries that are also experiencing better growing conditions. On the other hand, if the change in grass growth is negative, there will be lower production on the farm and an increase in demand for purchased feed from feed suppliers. The decrease in production will mean less milk for processors to process. This could negatively impact the ability to meet demand and reduce the level of exports.

A3.3.2 Heat stress

Dairy cattle are particularly susceptible to heat stress caused by high temperatures and humidity. This can affect growth, milk production and fertility in both sexes (Dunn et al., 2014). Susceptibility depends on the breed, genetics, feed intake, diet composition, normal temperature and production of the cattle (Yousef, 1985). Jersey cattle have been found to be less sensitive to heat stress than Holstein–Friesian cattle (Sharma et al., 1983). Bryant et al. (2007) found that cattle with high "genetic merit" (desirable breeding qualities), usually those with a high milk yield, are the most affected. This is because the increase in milk productivity is often related to increased feed intake, which heat stress negates (Kadzere et al., 2002).

Knox et al. (2012) conducted a study on the predicted effect of climate change on heat stress in the UK, which has a similar climate to the IOI. It found that loss of production due to heat stress will become relevant in the 2050s, when it is predicted to represent a loss of production of 0.03%.

When livestock are exposed to high temperatures their respiration rate, body temperature and consumption of water increase. At the same time there is a decline in feed intake (Seijan et al., 2015). This lowers milk yield and affects the quality of the milk (Bernabucci and Calamari, 1998). The milk produced has less protein and fat, and this content is the basis for the payments to farmers (Nardone et al., 1997). Heat stress also affects the fertility of livestock by reducing the level of reproductive hormone estradiol (Seijian et al. 2011). A decrease in fertility could have a large effect on a herd's milk production by reducing the number of lactating cows.

Climate change predictions suggest that temperatures will rise, which suggests heat stress will become a more common problem for dairy farmers. If, as is expected in the UK, it takes a long time for heat stress to have a noticeable effect on cattle health then farmers have plenty of time to adapt to and address this issue.

The decline in feed intake may result in a slightly lower demand for feed suppliers. It could increase the need for veterinary services to enhance the health of the cattle. It could also increase the need for artificial insemination, due to the lower fertility level. Processors may experience a drop in available milk for production that will be especially noticeable if the high temperatures are widespread.

A3.3.3 Natural disasters

Natural disasters can have a long-term effect on supply chains. The impacts can affect multiple growing seasons or production cycles. They may also cover a wide geographic area. The risks involve reductions in production and damage to assets such as farm buildings and machinery. Climate change is expected to have more of an impact on weather extremes than averages. Therefore, natural disasters such as extreme weather events are likely to increase in prevalence and intensity. The IOI is predicted to experience more flooding, droughts and an increase in storm intensity (Nolan, 2015).

A3.3.4 Flooding

Flooding from rivers, coasts, estuaries and groundwater poses a risk to dairy farms. Flooding can cause damage to animals, equipment and property. The frequency, degree and duration of flooding is predicted to increase due to climate change. Rain is the primary cause of most flood events (Office of Public Works, 2003). The increase in both extreme weather, such as high rainfall events, and the severity of storms will contribute to this.

Steele-Dunne et al. (2008) predicted that the increase in winter precipitation could lead to an increase in "stream flow", the rate and volume of water moving through a water channel at any time. They projected an increase of up to 20% from October to April when comparing the reference period (1961 to 2000) with the future period (2021 to 2060).

Wang et al. (2008) predicted that the number of storm surges will also increase by between 10 and 31%, comparing the period 2031 to 2060 with 1961 to 1990, depending on the location. The west coast of the IOI is particularly susceptible to this increase due to the proximity of the Atlantic Ocean.

Flooding causes many problems for farms. Morris and Brewin (2014) identified flood impacts to farms including the need to evacuate livestock to housing or flood-free areas, damage to pastures and grass production, loss of yield on crops, damaged drainage systems and field infrastructure, loss of beneficial soil biodiversity, and an increased risk of animal disease. These issues led to farm scale problems including extra expenses and loss of revenue. Expenses include the cost of purchasing feed, reseeding pastures, repairs to farm gates and drainage systems and the use of machinery to clear debris left behind.

Flooding of farms is beneficial to input suppliers, who will contribute to repairs and meet the increased need for purchased feed. Depending on the timing of the flood, it may also have an effect on production due to displacement of the livestock. It would also require producers to spend money either on flood insurance or to input suppliers, lowering the level of income farmers can earn. If these events happened frequently, the cost of insurance would probably rise, lowering profits for dairy farmers. Processors may experience a decline in the amount of raw milk available. Flooding may also effect transport links between the farms, processors and consumers.

A3.3.5 Droughts

Water is not generally a scarce resource on the IOI. Regional shortages can occur at certain times of the year, especially in the east and southeast of the island. Dry periods are expected to increase greatly over the entire island (Nolan, 2015). Water availability studies have not been conducted for agricultural land at the current time. Even so, this must be considered a major source of vulnerability for the island given the predicted reduction in rainfall due to climate change. Crops require a sufficient level of water to maximise yield. These crops are either grown on the farm or elsewhere as feed for dairy cows. Farmers require water for growing grass and fodder crops, hydrating cattle and cleaning especially at milking time. Processing the raw milk also requires large amounts of water.

The drought experienced by the IOI in 1976 resulted in a large rise in purchased animal feed (Stead, 2014). A severe drought may also affect the water supply for drinking water and cleaning that is required for milking. If the drought lasts for a long time, water may need to be transported from other regions to those that are most severely impacted.

Drought has a negative effect on production due to the lack of available feed and water. Grass growth would decline during droughts, requiring producers to purchase feed from suppliers. Processors would notice a decline in the available raw milk, leading to lower sales and the possibility of not being able to meet orders.

A3.3.6 Storms

Storms are predicted to decrease in number but track further south. Given the location of a large portion of IOI dairy farms, this trend is likely to result in a higher chance of storm-related problems. Storms are also predicted to increase in intensity. There is uncertainty relating to predictions about storms. This is due to the low number of previous storms fed into climate models. Storms have the potential to damage infrastructure, property, livestock and, if accompanied by heavy rainfall, contribute to the likelihood of flooding. As discussed in this report, flooding induces a large number of problems for dairy farms.

During the winter of 2013–14, the IOI was affected by a run of winter storms that led to serious coastal damage and widespread, persistent flooding (Met Eireann, 2014). This was caused by a southward shift in the polar jet stream[11] over North America. In 2012–13 it acted as a "conveyor belt" for weather systems that developed over the Gulf of Mexico and the Carribbean and then tracked towards Ireland and Great Britain. Storm force winds occurred for a total of twelve days, with rainfall increasing to twice the normal amount in some areas. This presents an example of the negative effects that increased storm activity over the southern part of the IOI can have.

Storms bring with them strong winds and heavy rainfall, both of which can cause significant damage to farms, requiring rebuilding and replacing of infrastructure and buildings. Livestock may need to be evacuated to safer areas, and stored fodder crops may be affected. The effects of flooding are described in detail in this report. Input suppliers would be required to repair the damage that occurs due to storms. As with flooding events, storms may have an impact on production, depending on the time of year. Storms could also damage stored fodder, forcing the purchase of more feed.

A3.4 Biological and environmental risks

Biological risks are generally associated with reductions in yield and quality. These risks are often localised and only affect a single production cycle. Consumers' increased awareness about the environmental footprint left by products is becoming a risk to downstream processors and distributors as they may turn away from dairy produce.

A3.4.1 Disease and pest distribution

Pests and pathogens have a negative effect on both animals and crops. Climate change may result in an altered ecosystem where both pests and pathogens will thrive. Bebber et al. (2013) found an average shift toward the poles in pests and pathogens since 1960. The persistence and spread of pests and diseases is likely to increase in a warmer climate. Expansion of vectors for bluetongue – in this case, the midges that carry this virus – and of airborne-spread foot-and-mouth is likely to increase. Livestock parasites may also increase substantially with just small changes in climate. The warmer winters are predicted to increase the survival rate of insect pests, which will increase their numbers considerably (Committee on Climate Change, 2016).

The IOI benefits from being geographically isolated on the edge of Europe. Being an island, it has a natural barrier that keeps out many pests and pathogens. However, animal transportation onto the

[11] The polar jet stream is the high, fast wind that flows, often erratically, from west to east around the northern hemisphere of the Earth.

island is likely to continue to be a major source of infection. The slightly warmer climate that is beneficial to diseases will also facilitate the faster spread of a disease when it arrives on the island. Forecasting of timing for this type of problem is imprecise; it comes down to chance.

Increased disease and pest distribution is a significant risk to the dairy supply chain that could cause problems of varying severity. If something similar to foot-and-mouth disease were to spread it would be a huge blow to the dairy industry. It would lead to a much lower supply of raw milk and a long recovery period.

At the other end of the scale, a small increase in the number of crop-damaging pests would have a lesser effect. This scenario would lead to an increase in costs, either for crop protection or for an increase in the amount of purchased feed required.

Animal-related pests and diseases will increase the need for veterinary services and possibly require more livestock inputs if it is a serious problem.

A3.4.2 Market-related risks

Market-related risk is generated by changes in supply and demand. This applies to the inputs and the outputs of the producer. Such changes in the market can affect the price, quality, availability and accessibility of products and services needed. Prices for both inputs and outputs are volatile creating uncertainty for producers. Climate change can increase this volatility, adding risk to the farmer. This is especially true for the IOI where diary is largely an export-based industry. As such, it is heavily reliant on international markets for both inputs and outputs.

A3.4.3 Feed availability and price

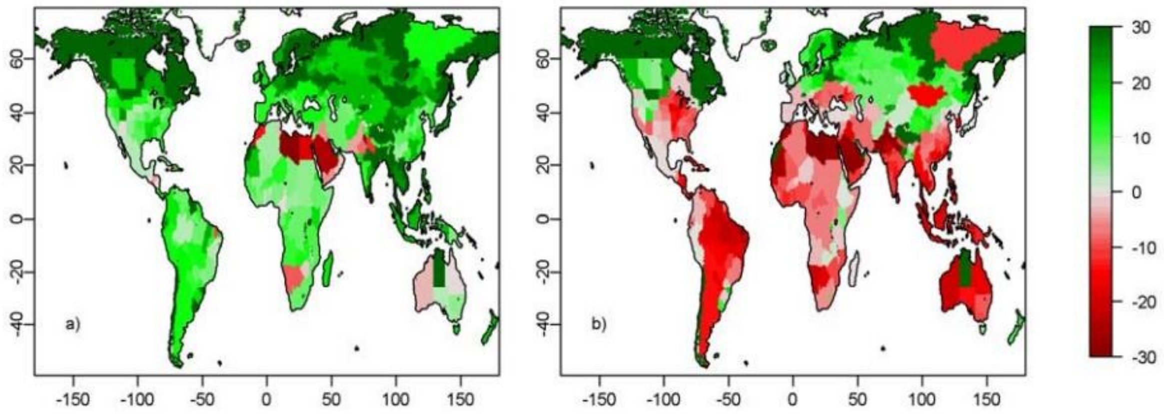
Grass production may increase on the IOI in the future. However, the removal of milk quotas and expected increase in the number of dairy cows means that feed concentrates and compound feeds will probably still be used in some quantity. Currently a large portion of the feed used in the dairy industry on the island is imported, mostly from Europe. Animal feed prices are volatile and climate change will aggravate this. An example of this effect occurred in the 2007–2008 food crisis when feed prices increased dramatically. A number of factors contributed to the crisis, at least one of which (a drought in Australia) was directly related to the climate change (Wright, 2011).

Global predictions about changes in crop production due to climate change are varied. The predictions of global changes in crop production made by Müller et al. (2009) are shown in Figure A.15. The diagram on the left (A.15a) includes full CO_2 fertilisation and predicts that most regions will experience increases in crop production by 2050. This is significant in the northern polar region, which is currently too cold for the majority of crops.

Without full CO_2 fertilisation, the predictions are shown as being vastly different (A.15b), with the majority of countries expected to experience reductions in crop production. Within Europe, the Mediterranean region is projected to experience decreases. The rest of the region, including the IOI, is expected to experience small increases in crop production. The impact of climate change on crop production in the future will largely depend on the level of adaptation within the industry.

Figure A.15: Predicted percentage change in crop production in 2050 over crop production in 2000. Scenarios are shown with full CO2 fertilisation (a) and without (b)

(A.15a) (A.15b)



Source: Müller et al., 2009.

Purchased feed and fodder is the biggest expense for both ROI and NI dairy farms. Changes in feed prices and availability have a significant impact on farm income. If crop prices increase in volatility this will limit the ability of farmers to plan, especially if there is a bad growing season domestically. The fodder crisis of 2012 and 2013 demonstrated what could occur more regularly in the future, with high feed prices due, among other things, to low international supply. This placed significant pressure on farmers who were suffering from a feed shortage with low grass growth for an extended period.

Milk production will likely decline during periods of high feed prices as farmers try to minimise costs. Farmers may also struggle to afford enough to meet the minimum requirements of their cattle, as happened in 2013, requiring government intervention. This will lead to less milk for processors who may in turn struggle to meet orders. The NI supply chain involves a higher utilisation rate of purchased feed at the production stage. It is likely to experience a stronger effect from the feed price fluctuations than in the ROI.

A3.4.4 Changes in consumer demand

The predicted increase in world population, along with increased demand from developing countries and rising incomes, is expected to increase demand for dairy products. However, there is some concern that consumers will consider the carbon footprint of dairy products and reduce their demand accordingly. Many studies have identified the consumption of dairy products as having a disproportionately adverse effect on the environment when weighed against the benefits of consuming them (United Nations Environment Programme [UNEP], 2010; Tukker and Jansen, 2006; Nijdam and Wilting, 2003).

Nijdam and Wilting (2003) estimate the contribution of milk, cheese and butter to total global warming potential is 4%. Tukker and Jansen (2006) suggest that 5.1% of the total global warming potential can be attributed to dairy products including fluid milk, cheese and dry, condensed and other dairy products. The UNEP (2010) study goes as far as suggesting that, to reduce the impact of agriculture, people worldwide need to consume less animal products in general.

Consumers are increasingly interested in sustainability. This has encouraged significant movement in the dairy industry to promote sustainability. Ornua, the largest dairy product exporter in the ROI, states that sustainability is an integral part of their business. The organisation provides information on how they encourage sustainable practices both on the farm and at other stages of the supply chain (Ornua, 2016). This involves “selling” the ROI’s predominantly grass-based farming to consumers as a sustainable alternative to housed (indoor) dairy systems that emit more GHGs (O’Brien et al., 2012).

Globally many arguments have been made in favour of a reduction in the level of meat and dairy products that people are consuming, to limit the environmental impact (Hedenus et al., 2014; Stehfast et al., 2009; Gill et al., 2010). Currently this is not affecting demand significantly. However, as the effects of climate change become more obvious to the public, consumers may change their behaviour. For the IOI dairy supply chain to contract, a significant reduction in demand would have to occur on a global scale.

A3.5 Public policy and institutional risks

Policy and institutional risks relate to the possible implementation of laws and regulations that directly affect the dairy supply chain. With regard to climate change, this is likely to involve mitigation strategies that attempt to control GHG emissions and minimise impacts. Agriculture contributes over 10% of global GHG emissions. Reducing this amount could make an important contribution to limiting the scale of climate change.

Policy makers must consider the environmental impacts of the dairy industry. However, they also need to take into account food security. This provides a sustainability dilemma for policy makers. Emissions policies and the CAP are the two sources of risk identified in this assessment.

Currently policy regarding climate change on the IOI is highly influenced by the EU. The recent "Brexit" vote in the UK places uncertainty on whether the UK (and NI) will remain in the EU. Exiting the EU means that NI and the UK would no longer fall under the scope of EU policy. Conceivably, future developments in the CAP may have no bearing on the NI dairy sector. However, the policies set in place by the EU may also be used as a benchmark for other nations and align with those of the UK.

A3.5.1 Emissions policies

Agriculture on the IOI emits a substantial share of the island's GHGs. Dairy is a large source of emissions due to the nature of livestock. The scrapping of EU milk quotas and the increasing demand for dairy products means that production will likely increase for the dairy sector on the IOI. With current efficiency and technology levels, this will lead to an increase in emissions from the sector. The Environmental Protection Agency (2015) projects that agricultural emissions in the ROI at least will increase by 2% between 2015 and 2020. Increasing emissions when many sectors are being required to lower their emissions may create pressure on the governments of both NI and the ROI to take action.

The government of the ROI has committed to reducing GHG emissions by 20% of 2005 levels by 2020. Heavy fines must be paid if these are not met. The EPA (2015) projects that non-Emissions Trading Scheme sector emissions will reduce by between 9 and 14% of 2005 levels by 2020. Agriculture and transport dominate these emissions. Agricultural emissions are expected to reduce by just 5% of the 2005 levels by 2020, This is a slightly better forecast than that for the transport sector, which is expected to experience a reduction from 2005 levels of 4% at best by 2020 (EPA, 2015).

Recently, new targets have been put in place for each EU member state for the period 2021 to 2030. The ROI is expected to reduce its emissions by 30% compared with 2005 levels by 2030. This places even more pressure on the government to continue efforts to reduce emissions.

While there are policies to reduce GHG emissions at national levels, currently there are no sectoral specific caps on emissions for the dairy sector. However, it is possible in the future that this may occur. Emissions caps or alternative policies will likely place limits on the level of production or reduce profitability if the policy requires the buying of emissions quotas. Alternatively, it may require compulsory purchase of technology or offsetting of emissions through other means such as tree planting.

The uncertainty concerning future abatement (harm reduction) policies may cause underinvestment in the sector as some policies could create strong negative effects on the profitability of dairy farming. Whilst soon the UK may not have to abide by EU emissions policies, NI dairy farming is still at risk from similar policies due to the global nature of the fight against climate change. Emissions policies will likely reduce production and cause the entire supply chain to contract.

A3.5.2 Common agricultural policy (CAP)

The CAP has moved substantially towards promoting environmentally friendly farming practices in the last 20 years. The main method of doing this is through "cross-compliance", where certain standards must be met before direct payments to farmers are made.

Changes to the CAP are made regularly. No one country can control the direction in which the CAP moves. However, each has some discretion as to how the policy is implemented within its borders. Future policies may be implemented to further reduce agriculture's impact on the environment and its contribution to climate change. This may include ways to reduce emissions.

The future of the CAP can not be predicted. Although the CAP is currently becoming more environmentally focussed with every reform, this may change if there are other more pressing issues concerning agriculture. If, for example, population growth creates issues for food security, the CAP may return to encouraging growth in the agricultural sector as its main goal. If water becomes scarcer, then this may be brought to the forefront within the environmental focus. The key point is that the change in policy could result in changes to the running of dairy farms, increasing costs or limiting production and resulting in a contraction of the dairy supply chain.

A3.6 Summary

Climate change poses many risks to the dairy supply chain. The impact and probability of these risks materialising varies and for some is not yet known. Risks such as heat stress, droughts and changes in consumer demand away from dairy products are unlikely to occur in the near future. However, changes in grass production, feed availability and prices and policy changes all represent real and current risks to the dairy supply chain that will only increase in both likelihood and size in the future.

Some research is already being conducted to identify possible adaptations that address some of the risks identified. This includes breeding more heat-resistant varieties of grass and crops and identifying the cattle with genetics better suited to certain environments. The vulnerability to these risks is dependent on the level of adaptation that takes place within the industry. Possible policy changes present a great degree of uncertainty. This is due to the current dilemma of the government between encouraging increased production in the dairy sector and reducing the environmental impact of the sector in the form of emissions and other pollution.

Appendix 4: Expert interview questions

A4.1 Part 1: Climate change and its relevance to your business

1.1: What does climate change mean to you?

1.2: What does climate change mean to the dairy industry in Ireland?

1.3: How will climate change impact your business requirements or needs?

(For researchers) 1.3: How will climate change impact your organisation?

1.4: Does your company have specific human resources dealing with climate action?

1.5: From the list below, please select the top 5 most significant risks facing your business sector today.

- Animal welfare legislation
- Animal disease
- Food safety risk
- Human health concerns regarding dairy consumption
- Capacity to process additional milk profitably
- Climate change
- Climate change related policies
- Volatility of dairy product prices
- Other, please specify

A4.2 Part 2: Addressing climate change

2.1: Who, if anybody, is responsible for addressing the impact of climate change?

2.2: What is the role of science and research in addressing the impact of climate change?

A4.3 Part 3: Addressing climate change

From our research, we have identified the following climate change related risks or critical factors for the dairy sector. Please rate the following statements on a scale of 1 to 7, where 1 = strongly disagree and 7 = strongly agree. Please provide a justification for your rating. Please rate how easy or difficult it is, in your opinion, to mitigate the impact of these risks and please explain what mitigation strategies you envisage.

3.1: There has been sufficient information relayed to your business sector regarding the impacts of climate change.

3.2: Extreme weather events are a major risk to my business sector.

3.2a: The impact of extreme weather events can be easily mitigated.

3.3: Changes in fodder and grass production as a result of climate change and extreme weather events are a major risk to my business sector.

3.3a: The impact of changes in fodder and grass production can be easily mitigated.

3.4: The emergence of heat stress for animals as a result of climate change is a major risk to my business sector.

3.4a: The impact of animal heat stress can be easily mitigated.

3.5: Increased disease and pest distribution as a result of climate change is a major risk to my business sector.

3.5a: The impact of increased disease and pest distribution can be easily mitigated.

3.6: The reduced availability and possible increased price of animal feed as a result of climate change is a major risk to my business sector.

3.6a: The impact of more expensive animal feed can be easily mitigated.

3.7: Consumers' concerns about the carbon footprint of milk production are a major risk to my business sector.

3.7a: The impact of these consumer concerns be easily mitigated.

3.8: Government policies to reduce GHG emissions from agriculture are a major risk to my business sector.

3.8a: The impact of such policies can be easily mitigated.

A4.4 Part 4: Mitigation strategies for climate change

Please rate the following statements on a scale of 1 to 7, where 1 = strongly disagree and 7 = strongly agree.

4.1: Policies to encourage reduced consumption of dairy products as a means of reducing (GHG) emissions have merit.

4.2: Improvements in animal genetics such as EBI (the Economic Breeding Index) have the potential to mitigate farm level dairy GHG emission in Ireland.

4.3: Even if science develops mitigation technologies that work, they will be adopted slowly by Irish dairy farmers.

4.4: Further reductions in the carbon footprint of Irish milk production will be a key selling point for Irish dairy exports.

4.5: The state should consider the possibility of providing Continuing Professional Development (CPD) training to better equip professionals in the dairy sector with the skills to address climate change in their business.

4.6: The development and expansion of forest areas for use in carbon sequestration has merit.

4.7: The application of the Sustainable Dairy Assurance Scheme is a worthwhile endeavour for Irish dairy farmers.

4.8: Milk processors should create financial incentives for producers to encourage them to produce milk in a manner that is more environmentally friendly.

4.9: Communication between Irish dairy farmers and environmental lobby groups regarding climate change is effective.

4.10: (a) I feel that the EU wants to tackle climate change too quickly over the next 10 to 15 years

(b) I feel that the Irish dairy sector will struggle to reduce its total GHG emissions in this period.

Do you have any additional information or comments you wish to add pertaining to the topics you have discussed today?

Appendix 5: Specific quotes supporting main themes emerging from interviews

Specific quotes that support the main themes that emerged in the course of the 20 interviews are provided here.

A5.1 Theme 1: The level of awareness of climate change and the need for collective action is high

- There is awareness amongst them, primarily due to Origin Green; the scheme is very well embedded throughout the industry.
- I think it's very good, looking at the range of stakeholders involved in the GHG Action Plan, definitely up to speed with the potential impacts on the businesses.
- From a marketing point of view, they feel it's necessary to be able to demonstrate that they are engaging on the issue, and that they are bringing about improvements.
- A whole of society approach is required; the flaw to date has been the focus on a sectoral approach, which has been divisive. An entire sectoral approach is needed, not a focus upon individual sectors. However, that's no excuse for the sector not doing all it can to deliver its obligations in so far as it can, without impacting upon output.
- There's a role of the different industries that have to adapt to climate change, not just the regulators. The regulators can set the benchmark, and everyone should be involved.

A5.2 Theme 2: Climate change may present an opportunity for the IOI dairy sector

- If the adverse conditions are less drought-related and more temperate, which is what is seems to be, then that in turn could lead to more plentiful grass, and having an abundant raw material source like that could be to our advantage.
- I think that we can stand over our production system, in terms of efficiency. We produce milk that is amongst the most carbon efficient in the world, and we're marketing our dairy products on the basis of our sustainability credentials, so I would see that as a strong point for us moving forward.
- Most efficient producers of dairy in Europe per kg of milk produced.
- Look at this for a great opportunity for the industry, market our milk as the lowest carbon impact in production, and not standing still, always be progressing.
- Origin Green is collating a lot of information regarding data, and that's a database that should be explored in terms of helping with scientific analysis.
- Bord Bia have done great progress with Origin Green, and other countries are looking to replicate this scheme

- I think Origin Green is where the thinking and the application is most advanced. Potentially, it is a differentiator, if the one unique selling point of an Irish product is that its sustainability is measured, it's controlled, it's reducing every year, compared to the other market, that's the differentiation.
- The marketplace is going to continue to demand that sustainability is addressed and built on. The marketplace is going to drive and demand the need for ongoing improvement around the climate and sustainability agenda.
- Customer desires to know about climate change will influence how we operate.

A5.3 Theme 3: Climate change may present a threat to the supply chain

- Another issue that would affect the feed industry is contamination of the feed chain, both in the raw material arriving at the ports and in feed that's delivered to farms. The establishment of Food Fortress was to help detect contaminations.
- If we get a bad crop in one part of the world, does that automatically mean that there's availability somewhere else? If there is, is it of similar quality, poorer quality? Maybe the pest control standards in those countries aren't as strong as where we're source it from now, and you could get into some potential food safety issues.
- We're not seeing extreme temperature events as such; we're seeing extreme water events. Extreme water events causes run off, cause pollution, which creates a whole series of domino effects, so you can see beach quality failures in summer after significant rainfall events.
- You can cope with the weather, but it's the frequency of which that weather occurs that's eats away at your ability to cope. A poor return one year in 10, you might be able to cope with, but looking at one year in five, well, you're not going to be able to recover from the previous events before the next one occurs.
- We do, in a general sense, deal with things when they arise, rather than plan for it.

A5.4 Theme 4: The challenge of putting research into practice

- With improvements in animal efficiencies, be it genetic, or the grazing season, or spreading of fertiliser, there's different technologies that can come on board, the dairy sector should be able to flourish.
- We cannot be complacent, so the role of research is critical in this regard. Need strong evidence-based policies that are informed by good, high quality scientific research.

- Rather than focus on technology, are the tools in place to allow farmers to respond to the climate challenge?
- There is a technology that can edit genes to potentially bring in some heat resistant genes, you can breed for disease resistance. Gene editing technology can help improve the mitigation of potential disease and pest distribution exasperated by climate change.
- Where we fall down in the messaging is that we need to explain more clearly that they're integrated, in terms of achieving economic security for themselves is intrinsically linked to more climate smart activities.
- We have implemented a few things, Digital Story project and also the carbon dairy project, all designed to show farmers that sustainability goes hand in hand with profitability, the more sustainable practices you employ, the better for your business.
- There isn't enough going on to translate that research [LiDAR] into what are quantifiable win–wins for farmers. One outcome should be presenting to farmers both the financial benefit as well as the carbon intensity benefit, which has not been done.
- There are three groups of farmers, the early adaptors that are very much into it, the second group, which tend to watch the first group and see what they do, and then you have the third, which don't seem interested in participating.
- Dividing the farmers up into groups which are willing to participate in agri-environmental schemes, a proportion of farmers are willing to engage with knowledge transfer and discussion groups, although some farmers can be less enthusiastic about participating in such groups, and more innovate methods are needed to find ways to move these farmers forwards towards environmentally sustainable practices.
- Knowledge transfer and farmer peer groups are essential in this regard, farmers may have difficulty engaging with policy makers and some advisors on issues like this, so discussion groups are imperative.
- Lots of great research is being done in universities, but how much of this research translates to real, practical operations? Somewhat of a disconnect of what researchers are developing and what is being released.
- How do you transfer this knowledge from research to the man on the ground, giving knowledge from researchers to farmers. There's a massive gap there. Implement what you already know onto the farm, because not everything that worked in the lab may work on the farm.
- We've a lot of R & D done which hasn't been real world validated. A lot of blue sky rocket scientists doing things which are not market driven, in any shape or form, and that's very bad science. First part of exercise is, Does the science work, and second part, Is it commercially viable, and does it work in the real world? That needs to be part of the process, though it tends to be missing.

A5.5 Theme 5: Policies relating to climate change are a concern for the sector

- There is a tendency to have research on how to cope with the problem, rather than addressing it.
- Their laid back approach [Government] will not fix this problem. Action has to be taken, and I think it's policies that will cause this to happen. Targeted areas for policies, looking at the bigger picture, look at getting the overall figure down, rather than looking at smaller sections.
- Possible constraint upon production. Traditional constraints have been land, labour and capital, maybe we're seeing environment as the fourth constraint. An issue that is present is that the policy at the moment is a "one size fits all", so it suits certain economies that are more heavily dependent upon energy and transport, where there is the possibility of easier mitigation. Whereas Ireland's emission profile is composed of 33% from agriculture, there are limited mitigation options in this sector, and so that poses a challenge.
- The importance of presentation of future policies, including solutions and incentives. Really work the policy out first, make sure that farmer discussion groups and Teagasc get a good input into what they do. Present them with the options, and actually work out, from a feasibility point of view, if they can be done.
- There is a demand out there for dairy products. There are benefits to dairy products, and also alternatives to dairy products. At this moment in time, Ireland is THE place on the planet to sustain this demand, and with less impact on a global scale, owing to our pasture grazing system.
- Globally, consumers are going to look at continuing to consume dairy products, and the challenge, for countries such as Ireland, is to become the most carbon efficient in terms of providing that extra product.
- The argument of carbon leakage is a real one, which is if we are to reduce our emissions, the market demand will be met by someone else not as efficient. So, by us producing dairy products, at least it's the most efficient way of producing it.
- This is a very good region to produce dairy products, we're good at it, we've a history of it, we have a lot of grass, and we will be better at GHG emissions than almost anybody else, because we will make it our business to be better. If we're going to export 80% of our dairy out, then the metric need to reflect the output, not relative to our population, it has to be done on a global calculation. Effectively, we're producing this product and it's eaten somewhere, we've incurred the GHG for that product here, but had it been produced over there, the GHG costs could have been higher.
- There should be an element of an intensity calculation. If we were to reduce our output in order to reduce GHG emissions, then dairy products will be sourced from other countries, maybe those whose environmental standards are not as sufficient as Ireland's, and who could produce more GHG emissions.

A5.6 Theme 6: Forestry as a mitigation strategy

- Land management, in a very obvious way, will take carbon out of the atmosphere, and it's important to identify appropriate lands.
- Soils have a big part to play; I think that 90% of the soils in the country are not being optimised, so there's a big pH imbalance. Even if you addressed this, 1.8 million tonnes of carbon could be sequestered.
- Only 10% of our area is covered in forestry. EU average is much higher, and this would help to contribute to CO2 mitigation. If we increase our plantations to 8,000 ha per annum that could result in 4.2MT of CO2 saved.
- Looking at land uses, things like agro-forestry, rather than mainstreaming forestry as a competitive enterprise to dairy, agro-forestry can live in harmony where it's almost part of the dairy farming practice, it complements the industry, it doesn't compete with it.
- Having a farm income based upon one source may not be working for some, if you could have more diversification in income, could work towards building resistance towards flooding impacts and price volatility, in terms of farm income.
- I think there's one huge gap, and that's the role the ruminant landscape plays in milk production. Using a technology called LiDAR, to work out accurately how much wood was in trees and hedges on farmlands, work out how much carbon was in it, and then you can predict how much of those are going to sequester GHG on an annual basis. Gives a reason to manage habitats better, multiple wins.

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*safe*food:

7 Eastgate Avenue, Eastgate, Little Island, Co. Cork

7 Ascaill an Gheata Thoir, An tOileán Beag, Co. Chorcaí

7 Aistyett Avenue, Aistyett, Wee Isle, Co. Cork

Tel: +353 (0)21 230 4100 ***Fax:*** +353 (0)21 230 4111

Email: info@safefood.eu ***Web:*** www.safefood.eu

www.safefood.eu
HELPLINE
NI 0800 085 1683
ROI 1850 40 4567