NUI MAYNOOTH
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SUSTAINABILITY OF INTENSIFIED AGRICULTURAL PRODUCTION IN THE BOYNE CATCHMENT

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Abstract

Food Harvest 2020 is a national plan for intensification of agriculture with specific targets to be delivered by 2020. The plan envisages increases in output across a range of farm enterprises – dairying, beef, sheep and pigs. The motivation for this study was to examine the environmental sustainability of the Food Harvest 2020 targets. The study was carried out on the River Boyne catchment area.

A wide-ranging environmental systems analysis was carried out to assess the environmental impacts associated with the intensification of agricultural production envisaged in Food Harvest 2020. The following environmental impacts were assessed using Life Cycle Assessment (LCA) modelling: Global Warming Potential, Primary Energy Use, Eutrophication Potential, Acidification Potential, Abiotic Resource, Pesticide Use and Land Use. Ideally, one would aim for a full LCA approach for all commodities in the agricultural sector. However, this was not possible because of the complexity. The scope of the study was therefore limited to 10 arable crops and 4 livestock production systems.

Following an extensive review of the literature and consultation with expert opinion, the Cranfield LCA Systems Model was selected to carry out the analysis. This model proved to be very suitable as it was specifically developed for agricultural purposes.

The modelling identified significant increases in environmental burdens associated with intensification of milk production, beef production and pig production. There are a number of strategies that could mitigate or offset to some degree the increased environmental burdens. The recommendation from this study is that the implementation of Food Harvest 2020 should be tied to a package of transparent and verifiable mitigation measures. Some of the mitigation measures may be cost neutral and others may not. In any case business as usual is not a sustainable scenario.

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Chapter 1:

Introduction

1.1 Global Food Security: Supply and Demand

The United Nations Food and Agriculture Organisation (FAO) defined Food Security as a state where "*all people at all times have physical and economic access to sufficient, safe and nutritious food for a healthy and active life.*" (FAO, 2008:1). The food security challenges are both immediate and long term.

According to Keating (2010:1) "*The challenge for agriculture in the coming decades will be to increase productivity of agricultural lands in line with increasing demands for food and fibre.*"

The World Development Report (World Bank, 2008) has predicted that cereal production would have to rise by 50% and meat production by 85% from 2000 to 2030 to satisfy increases in food demand. In the longer term, economic development trajectories (including changes in diet preferences towards more meat and dairy products and increase in global population to 9 billion) suggest an increase in food demand in the order of 75% between 2010 and 2050. Even the most optimistic scenarios require increases in food production of at least 50% (Royal Society, 2009). Globally, due to advances in technology, average yields for all the major cereals increased steadily from the 1960s to the 1990s (World Bank, 2008). Most of the progress was due to yield increases rather than expansion of the areas cultivated. Africa was an exception, however, and most of the increase in output (60%) from sub-Saharan areas was due to expansion of the areas cultivated. Since 1995, the rate of global progress towards higher cereal yields (wheat and rice in particular) has tended to level off (World Bank, 2008). This raises concerns for the attainability of the food production targets required to feed 9 billion people. The extent to which climate change will impact on global food production is subject to large uncertainties but it is likely that climate variability and change will exacerbate food insecurity in areas currently vulnerable to hunger and undernutrition (Wheeler and von Braun, 2013). While growth in demand for food is inevitable, the extent of the increase is difficult to quantify and estimates vary widely. It will depend, in no small measure, on how far policy on the demand side is successful in modifying diets, reducing waste and reducing the rate of population growth (Garnett and Godfray, 2012).

Von Braun (2007) and Conway (2009) have succinctly identified the drivers for chronic food insecurity as follows:

- Changing and converging consumption patterns
- Increasing per capita incomes, leading to increased resource consumption
- Growing demands for livestock products (meat and dairy)
- Growing demand for biofuels
- Increasing water and land scarcity
- Slowing of increases in agricultural productivity
- Adverse impacts of climate change

It is clear, therefore, that a multipronged approach is required to address the multiplicity of factors involved.

Climate Change vs. Food Security: An intractable conundrum?

The last cited point above emphatically underscores the prediction that climate change will exacerbate food security for some of the most malnourished peoples of the world. Modern food production systems by their nature (high resource use and high emissions of greenhouse gases) have the potential to exacerbate climate change. Going forward, there is an inherent conflict between measures to increase the global food supply and measures to keep climate change within safe limits. Increasing global food production in line with future demand is likely to introduce positive feedback mechanisms that could render the climate change scenario even more precarious. Sustainable intensification is now a much used term in relation to the future of agriculture and food security (Garnett and Godfray, 2012). Sustainable intensification has been defined as a form of production wherein “yields are increased without adverse environmental impact and without cultivation of more land” (Royal Society, 2009:1). In reality this is aspirational. There are always some environmental impacts associated with intensification of agriculture. Increased use of nitrogen fertilizer increases the emissions of nitrous oxide, a potent greenhouse gas. Increasing stocking densities of ruminant animals increases the amount of methane gas emitted. In the process of feeding 9 billion people, probably the best that can be attained is a reduction in adverse environmental impacts per unit of product, allied to the absolute minimum of extra land brought into cultivation.

Another issue listed above as a driver of food insecurity is the increasing demand for biofuel. The subsidised production of ethanol from corn is believed by some researchers to be of negative benefit in the climate change balance sheet when all relevant emissions are taken into account (Searchinger *et al.*, 2008). Of great concern is the use of top quality arable land for a non-food crop. Arguably, sugar and starch-derived biofuels could be replaced by other forms of renewable energy e.g. wind farms and solar power. This would free up large areas of land for production of food, potentially limiting the amount of land use change (LUC) from natural ecosystems. Conversion of equatorial forests to food production has a significant impact on climate change caused by large emissions of greenhouse gas (Cederberg *et al*., 2010; IPCC, AR4, 2007). Searchinger *et al*. (2008) found that previous analyses had failed to count the carbon emissions that occur as farmers worldwide respond to higher prices and convert forest and grassland to new cropland to replace the grain (or cropland) diverted to biofuels. By using a worldwide agricultural model to estimate emissions from land-use change, they found that corn based ethanol, instead of producing a saving, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years.

Growing demand for livestock products (meat and dairy) was listed above as another driver of food insecurity. It is also a driver of climate change because of high greenhouse gas production associated with ruminant animal production systems in particular. Even more damaging from a climate change perspective, some of the beef traded on world markets is associated with deforestation. Cederberg *et al* (2011) identified the expansion of pastures for beef production in South America as a key driver of deforestation. They found that in Carbon Footprint calculations for beef, emissions from land use change (LUC) are not routinely included. When emissions from LUC are included, Brazilian beef is seen to have a very high Carbon Footprint. Brazil is one of the dominant players in world beef trade and the country has aspirations to almost double exports of beef in the decade to 2020. Large retail chains (and their customers) have the power to change agricultural practices by sourcing food products with low Carbon Footprints. By so doing, they can have a significant effect on the climate change balance sheet.

1.2 European Union Food Policies

Since the Treaty of Rome (1957), secure availability of food has been a cornerstone of policy and a laissez faire approach has been strongly resisted by most member states. This was the driver for the introduction of the Common Agricultural Policy (CAP). Article 39 of the Treaty of Rome (the agricultural article of the Treaty) recognises, and indeed aims to encourage the trends towards increased productivity and consider this to be the most important method of ensuring “a fair standard of living for the agricultural population.” Further objectives (stated in Article 39) are to ensure reasonable stability of food supply and reasonable prices for the benefit of consumers. The imperative of achieving food security has been used to justify many interventions in the market to support farming and rural communities. Intervention purchasing of surpluses has been a central element in the CAP price support system for some major products from the outset. This resulted in farm product prices that were, in general, well above world market prices. It could be argued that the CAP policies were too successful, as large surpluses of food commodities built up in the 1970s and 1980s. The cumulative effect of the policy changes detailed below was to curb production and bring supply and demand into better balance.

Until recently, the policy driving forces in production of milk, beef and sheep meat were towards extensification. Milk production across the Community was capped at the 1984 level by milk quotas. Milk producers in Member States and their processors managed milk supplies to avoid incurring a super-levy on surplus production. Excessive beef and sheep meat production in the EU was tackled by the introduction of the Single Farm Payment (SFP) in 2003, under which payments (subsidies) were decoupled from intensity of production i.e. a severing of link between production and support. This represented a fundamental reform of the CAP. The Single Farm Payment is linked to meeting environmental conditions, public health, animal and plant health and animal welfare standards and the need to keep land in good agricultural and environmental condition. Effectively, famers could choose to wind down farming activity and still receive their SFP as long as they adhered to good environmental practices. In the Irish context, decoupling of direct payments did not result in the radical changes in the beef and sheep sectors that were anticipated. The majority of cattle and sheep farmers continued to derive 100% of their net income from direct payments as product prices would, in most cases, not cover costs of production. Although they could have chosen to de-stock and retain payment levels, the majority opted to maintain animal numbers on their farms despite the absence of financial reward for doing so. The EU funded Rural Environment Protection Scheme (REPS), introduced under Council Regulation 2078/92, set limits on stocking density i.e. rewarded low-medium intensity production. Organic food production was also supported by financial incentives. The introduction of the EU Nitrates Directive (91/676/EEC) limited the amount of fertilizer that could be used in livestock production. Although the objective of the directive was to safeguard the quality of water resources, it also had the effect of curbing livestock production.

The milk quota system is due to be abolished in 2015. In reality, this represents an opportunity for sustainable intensification of milk production to meet the increasing worldwide demand for dairy products.

Over the last 40 years, Ireland's membership of the EU has had its ups and downs and while CAP may have its staunch supporters and vocal critics, it is difficult to deny the benefits and opportunities it has delivered to Irish farmers and the wider Irish economy. It heralded exposure to new markets and, therefore, the opportunity to increase export trade. Not least of the benefits was the €50 billion paid to Irish farmers over the 40 years.

1.3 Change in Irish Agricultural Policy: Intensification replacing Extensification

In line with new thinking on the global food security agenda, there is a significant motivation towards policy change where Irish food production is concerned. As a food exporting nation, Ireland with its climatic advantage and clean green image is well placed to supply greater quantities of livestock products to the global food market. Inherent in this scenario is sustainable intensification of production i.e. a reversal of the extensification approach that prevailed in the era of over-production of food products, milk and beef in particular. Broadly, intensification refers to increasing the levels of inputs (e.g. fertilizers, energy, concentrated feed) to produce more output (e.g. milk, beef and lamb) from the same area of land (Basset-Mens *et al*., 2007). In the Irish context, intensification is embodied in the Food Harvest 2020 programme.

Irish Climate Change Issues related to agriculture

Intensification of Irish agriculture going forward is predicated on climatic conditions that are highly favourable for growing grass. It is important to examine the possible effects of climate change on the future sustainability of grass based ruminant livestock production systems in Ireland. This is of particular importance to young farmers or those about to take up a career in farming. The vulnerability of these systems to extreme weather events was evident in Spring of 2013 when lower than normal temperatures up to mid-May and consequent poor grass growth, heralded a fodder crisis on many farms. Climate modelling projections have indicated that substantial precipitation changes may occur in Ireland by mid- century (Sweeney *et al.*, 2008). The projections would indicate increases in rainfall in general but up to 20% more rain in the northwest. This could result in longer winter housing periods for livestock due to adverse ground conditions for grazing, particularly on heavy, water retentive, clay soils. This scenario would be likely to impose extra costs associated with provision of extra winter feed on farms. In contrast, the rainfall projections for the summer months are for decreases of 25-40% on present values across eastern and south eastern parts of the country. This could impact significantly on grass growth potential especially on areas with light soils. On the other hand, drier warmer weather would be ideal for the growing of forage maize.

1.4 Food Harvest 2020 Plan

The Food Harvest 2020 (FH2020) is a government and industry-led blueprint for agricultural production over the next few years, culminating in the achievement of set targets for each sector in the year 2020. In this study, the targets of FH2020 are applied pro-rata to the Boyne Catchment.

The projected increases in agricultural output envisaged in Food Harvest 2020 are substantial and as set out below, represent a reversal of the extensification policies of recent years.

Dairy Sector

The planned output increase in milk production is 50%. Increasing output will be required which implies substantial intensification of production. Intensification can be thought of in terms of increasing stocking density (e.g. more cow numbers per hectare) and progressive increases in milk yield per cow. Almost inevitably this will be accompanied by increased use of fertilizer and other inputs per hectare. Increased milk production per hectare can be achieved by producing more grass on the farm, through higher use of nitrogen fertilizer or alternatively by importing higher quantities of feed supplement on to the farm.

Beef Sector

There is no volume target set, but rather an increase in value of 20%. It seems reasonable to infer that most of the ‘value target’ will be met by increases in price as demand for beef worldwide continues to increase. Extra calves coming from the dairy sector will provide raw material for increasing output. Suckler cow numbers may decrease, if significant numbers of farmers switch over to a more profitable milk production enterprise. Beef farmers may also get involved in the contract rearing of replacement dairy heifers for specialized dairy farms. The most likely scenario is for a small increase in intensity of production in the beef sector.

Sheep Sector

Here again there is not a volume target built into FH2020. There is a 20% increase in value output. It seems most likely that volume will remain about the same as the baseline and that the projected value output will be delivered by increases in the price of lamb.

Pig Sector

Under the FH2020 Plan a 50% increase in output is projected for this sector. If implemented pro-rata in the Boyne Catchment, the extra nutrient loading has to receive very careful consideration indeed. There is a clear distinction between agricultural activities where the number of livestock is limited by the land available (closed system) and intensive units where no such limiting factor applies (linear system). According to Courtney (1986), conventional pig farming has taken on many of the characteristics of industry e.g. large scale production, concentration on one product, strong emphasis on labour efficiency and other cost cutting measures. Accordingly, these methods of food production have been referred to as "factory farming."

Arable Sector

Under FH2020, no targets have been set for the arable sector. The most likely scenario is a slight decrease in area of crops, as dairy farmers seek to acquire more land to enlarge their holdings. The distribution of individual crop areas may change. The area of maize silage is likely to increase at the expense of cereal area to provide more feed for dairy farms.

Environmental Content of the Food Harvest 2020 Plan

The authors (Brady *et al*., 2009:22) of the Food Harvest 2020 document acknowledge that challenging environmental issues loom large and need to be addressed in scientific ways:

"It is important to recognise that agricultural activities can negatively impact on water, soil and air quality as well as biodiversity. Meeting the ambitious growth targets set out in this vision means meeting, head on, these environmental challenges as well as reducing the carbon intensity of Irish agriculture and ensuring Irish agriculture plays its full part in reducing our overall greenhouse gas (GHG) emissions."

The authors go on to list areas for environment-related action:

- Promoting sustainable pasture-based farming and soil management
- Contributing to sustainable energy requirements
- Developing new green technologies that improve water quality
- Reducing the carbon intensity of agricultural activities and enhancing carbon sinks

- Contributing to protecting biodiversity and achieving biodiversity targets

In line with the global food security agenda, the policy of the agricultural and food production sector and the Irish Government has shifted from relatively extensive production to sustainable intensification of agricultural production across a range of products. The new policy is embodied in the Food Harvest 2020 Plan. The motivation for this study is to examine the environmental sustainability of the higher output regime of Food Harvest 2020 across a range of environmental impact categories.

1.5 Selection of a target area for the study

It was decided to select a mixed farming area with good standards of commercial farming. The selected area would have to support a wide range of arable crops and livestock enterprises that would be in line with the Food Harvest 2020 Plan. The River Boyne catchment area was chosen for the study because the wide diversity of farm enterprises facilitated a realistic environmental assessment of the environmental consequences of Food Harvest 2020.

General Description of the Study Area

The River Boyne flows in a roughly north-eastern direction from its source for about 112 km before entering the Irish Sea at the port of Drogheda (Fig. 1.1). Along with its network of tributaries, it drains a catchment of approximately 2,500 km^2. The main channel has a low average gradient of 1.24 m/km, representing a fall of only 140m from the headwaters in North Kildare to the sea. This makes it one of the flattest river gradients of the major Irish rivers.

Climate Change Issues for the Boyne Catchment

Rainfall in the Boyne Catchment ranges from approximately 830mm per year in the central area (Trim, Navan and Drogheda) to approximately 1,100 mm per year in the Bailieboro area of Cavan (northern part of the catchment). The long-term average yearly rainfall for the catchment as a whole is of the order of 920 mm. Since the catchment is an important agricultural area for arable crops and livestock production it is important to examine recent projections for climate change in the area. The amount of water stored in the soil is fundamentally important to agriculture. The local effects of climate change on soil moisture will vary not only with the degree of climate change but also with soil characteristics. The water holding capacity of a soil will have an effect on soil moisture deficits. The lower the water holding capacity, the greater the sensitivity to climate change (IPCC, 2001). The main soil types in the catchment are Grey Brown Podzolic, Gley and Acid Brown Earth. These soil types are characterised by good water holding capacity and would be able to support reasonably good grass growth at soil moisture deficits up to 40 mm. Localised areas of light texture soils with low-clay and low organic matter would not however be expected to support good grass growth in dry summers and especially in periods of drought. In modelling climate change effects for the Boyne catchment, Murphy *et al*.(2005) found significant effects as early as the 2020s. In the case of upper soil (i.e. the top soil or A Horizon), there is a decrease in water storage for almost every month of the year by the 2020s, the greatest decrease being in late summer and early autumn. The cumulative increase in soil moisture deficit could have an adverse impact on grass growth for the July-September period. On the other hand, this type of climatic change would be expected to be beneficial for forage maize and cereal crops. The Boyne Catchment is an important potato growing area and the ‘drier summers scenario’ would require a plentiful on-farm supply of water for irrigation of the crop, a situation that might be difficult and expensive to sustain.

Groundwater storage and the extent of its recharge will be important for many farmers who use wells to supply water for domestic and farm use. For example dairy cows require 6 litres of water for each litre of milk produced. There are additional water requirements for milk cooling and washing of dairy equipment. Based on precipitation scenarios, Murphy *et al*. (2005) show reductions in groundwater for all months of the year during the 2020s. Although, they have stressed that precipitation scenarios are less reliable than temperature scenarios, nevertheless, if the projections are borne out, reduction in water availability may have a bearing on the long term sustainability of the Food Harvest 2020 plan.

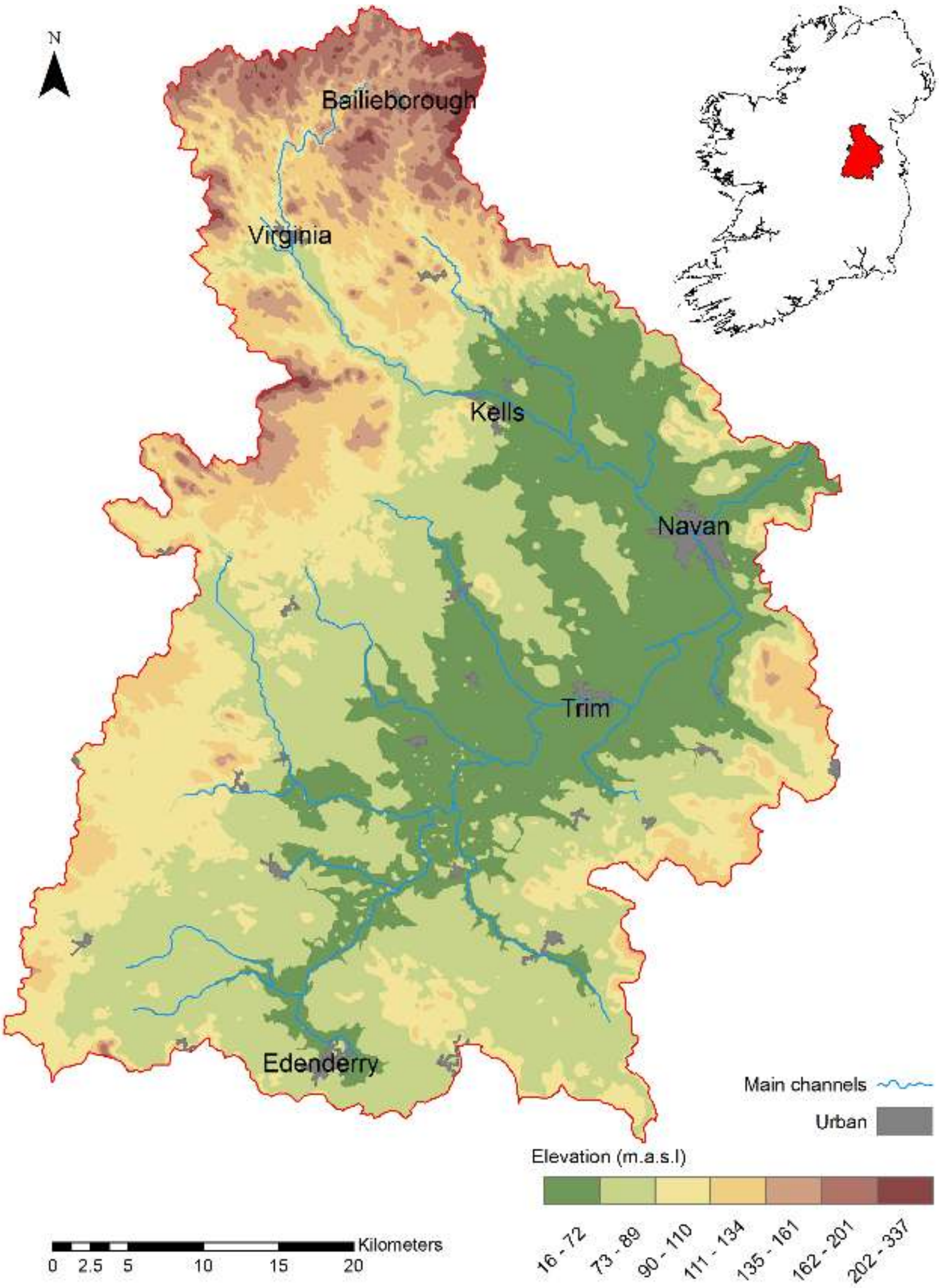


Fig. 1.1: Location Map of Boyne Catchment

Source: Harrigan (2013)

1.6 Examining Sustainability of farming systems in the Boyne Catchment

The environmental sustainability of the FH2020 targets need to be assessed across a range of environmental impact categories for the target area – Boyne Catchment. This is the rationale for the present study. The activity data for the Boyne Catchment were assumed to increase pro-rata with the FH2020 national intensification targets for each of the commodities. The research addressed key questions on sustainability of agricultural production within the catchment:

1. What are the burdens (environmental impacts) associated with the baseline (average 2007,2008, 2009) levels of production?

2. What are the burdens (environmental impacts) projected for the levels of output envisaged in the more intensive Food Harvest 2020 plan?

3. What are the increased burdens and are they sustainable?

4. Can the environmental impacts identified be partially mitigated or offset by actions at farm level?

1.7 Environmental Impact Categories associated with agricultural production

The commonly quoted and analysed impact categories associated with agricultural production systems can include any or all of the following:

Global Warming (Climate Change)

Global Warming Potential (GWP) is used to assess the ability of different greenhouse gases to trap heat in the atmosphere. The greenhouse gases associated with agriculture are for the most part Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O). GWP is calculated using timescales of 20, 100 and 500 years, of which 100 years is the one most often quoted. GWP is calculated to a standard reference benchmark of CO_2 equivalents (Williams et al., 2006).

The GWP_{100} values given in the most recent Intergovernmental Panel on Climate Change (IPCC) guidelines (2006) are as follows:

Table 1.1 Global Warming Potential of Agricultural Greenhouse Gas emissions

Substance	GWP100 [kg CO_2-equiv.]
Carbon Dioxide (CO_2)	1
Methane (CH_4)	23
Nitrous Oxide (N_2O)	296

In view of the substantial increases in output envisaged in Food Harvest 2020, there is an urgent need to identify low carbon pathways for development of the livestock sector in the Boyne Catchment, in particular for the dairy, beef, and sheep sectors which are high greenhouse gas emitters.

Eutrophication Potential (EP)

The main agricultural causes of eutrophication are Nitrate (NO_3) and Phosphate (PO_4) leaching or running off to water courses and (indirectly) Ammonia (NH_3) emissions to air. EP is quantified in terms of Phosphate equivalents: 1 kg NO_3-N and NH_3-N are equivalent to 0.44 kg. and 0.43 kg PO_4 respectively (Williams *et al.*,2006)

The Boyne Catchment has a history of water quality problems, the most prominent being lacustrine eutrophication in the upper reaches of the Kells Blackwater. The projected increase in product output associated with Food Harvest 2020 will require an increase in livestock numbers leading to higher nutrient loading (nitrate and phosphate) in the catchment. This could render the targets of the Water Framework Directive much more challenging to attain. The starting point would be to assess the Eutrophication Potential associated with the baseline production activity (average of 2007, 2008, 2009) and then for the increased intensity associated with delivery of the Food Harvest 2020 intensification programme.

Acidification Potential (AP)

Acidification Potential is an assessment of the potential for damage when acidifying substances result in a decrease in pH of natural habitats. Acidifying pollutants have a wide range of environmental impacts on soil, ground water, surface water, biological organisms and damage to buildings (Basset-Mens *et al*., 2007). Ammonia gas (NH_3) is volatilized into the air mainly from slurry in storage or post-spreading in the field. Ammonia contributes to Acidification Potential and (indirectly) to Eutrophication Potential as well. Although Ammonia is alkaline it oxidises to Nitric Acid in the atmosphere. Emissions of Sulphur Dioxide (SO_2) associated with burning fossil fuel is also a contributor to Acidification Potential (Williams et al.,2006). Acid deposition can be close to the emission site or a long distance from the site, even beyond national boundaries.

Primary Energy Use:

The main fuels that support agricultural production in the Boyne Catchment include diesel, electricity and gas. Williams *et al*. (2006) quantified these in terms of the primary energy needed for extraction, refining and delivery of the fuels (otherwise known as energy carriers). They are quantified in units of MJ (megajoules) primary energy. They range from approximately 1.1 MJ natural gas per MJ of available process energy to 3.6 MJ primary energy per MJ of electricity. At present a small (but growing) proportion of electricity is generated from Renewable Energy Feed in Tariff (REFIT)-supported renewable sources such as wind and biomass. The Edenderry peat-fired power station is required to co-fire with biomass, mainly willow woodchip. Other renewables will be explored during the course of this study.

Abiotic Resource Use

Abiotic resources include fossil reserves and mineral resources, although by definition all are non-renewable in the short term. They may be plentiful like Limestone or in limited reserves like phosphate. Abiotic resource use was one of the impact categories used in this study.

Land Use

There are opportunity costs attached to land use. Productive land is a limited resource. Land use was another one of the selected impact categories.

Pesticide Use

Pesticide use was also assessed as an impact category in this study.

1.8 Options for environmental systems analysis related to Food Harvest 2020

One of the prime objectives of the literature review was to identify a suitable model (or models) that would quantify the environmental burdens and resource use associated with Food Harvest 2020 across a range of environmental impact categories. Environmental Life Cycle Analysis (LCA) is a highly regarded holistic methodology for quantifying these. Although LCA has a long history in manufacturing industry, its use as an environmental assessment tool in agriculture is more recent.

Many recent Life Cycle Assessments (LCAs) have focused on the single impact of Global Warming Potential. These include Carbon Footprinting of Irish beef farms using the PAS:2050 LCA model (developed by the British Standards Institute) and with follow up certification by the Carbon Trust (Bord Bia, 2011).

LCA will be used to evaluate the environmental impacts and resources associated with the increased output scenario inherent in the Food Harvest 2020 plan.

1.9 Thesis Structure

Chapter 1: The introduction gives a brief profile of the target area. An outline of Food Harvest 2020 is given. The environmental impact associated with this programme of intensification was the motivation for this study.

Chapter 2: Literature Review. The main focus of the review was to examine methods used by other researchers in assessing and quantifying the environmental impacts of agricultural production. A wide ranging review of 30 papers relating to LCA has led the author to conclude that the best holistic model for use in this study is the Cranfield LCA Systems Model.

Chapter 3: This chapter gives a profile of agricultural production (arable and livestock systems) in the Boyne Catchment area.

Chapter 4: Methodology used in the study. The environmental impacts associated with intensification of agricultural production in the target area were calculated using Life Cycle

Assessment. As stated above, the model selected for use was the Cranfield LCA Systems Model.

Chapter 5: Environmental Systems Analysis of crop production in the Boyne Catchment area. A range of 10 arable crops was assessed for environmental impact, pre and post intensification.

Chapter 6: Environmental Systems Analysis of livestock production in the Boyne Catchment area. The following enterprises were examined for environmental impact assessment: Milk production, Beef production, Sheep production, Pig production. Modelling was done for the pre and post intensification scenarios.

Chapter 7: Mitigation: Strategies to address the environmental burdens identified in Chapters 5 and 6 were explored. In general, there is an examination of the possibilities at farm level for offsetting some of the burdens associated with implementation of FH2020.

Chapter 8: Discussion and Conclusion. This chapter deals with observations arising from the research project on the sustainability of agriculture in the Boyne Catchment under the Food Harvest 2020 intensification regime. It also puts forward some recommendations for future action.

Chapter 2

Literature Review

2. Introduction

Assessing the extent to which agricultural production impacts the environment is not a simple exercise. It involves the selection of an appropriate range of environmental impact categories for the target area or product and using appropriate tools for their measurement. This called for a thorough and wide-ranging review of the appropriate literature.

2.1 Environmental Impact Assessment Tools: A review of the literature.

IPCC versus LCA.

O'Brien *et al.* (2010) employed a dual purpose economic-GHG model to calculate the GHG of 9 pasture-based Irish dairy farms using:

1. IPCC Method (Intergovernmental Panel on Climate Change)
2. Life Cycle Assessment (LCA) method.

Based on the results, O'Brien cautioned about an over-reliance on IPCC methods. He recommended the use of the more holistic LCA methodology. He suggested that LCA would account for upstream emissions associated with the manufacture and distribution of inputs to farms. Examples of these would be fertilizer and pesticide manufacture, feed compounding and energy supply. Use of LCA could account for all processes up to the stage where milk leaves the farm gate. In one scenario, O'Brien found that using the IPCC method, high input dairy systems, with a totally mixed ration, reduced emissions per unit of product by 3% (compared with the control) whereas when LCA was used this type of system increased emissions by 8%. Both methods (LCA and IPCC) indicated that low input dairy systems reduced GHG emissions per hectare by 10-20%. However, when emissions were expressed per unit of product, the methodologies did not rank farming systems in the same order. This would tend to suggest that area based indicators are less useful than product based indicators in quantifying GHG emissions from livestock production systems. O'Brien *et al*. (page 15) goes on to suggest that "*producers could implement strategies* which *comply* *with policy methodology (IPCC method) and reduction targets, but when a holistic analysis is conducted, the net effect of complying with the policy is to increase emissions to the environment. The results indicate that if abatement strategies targeting a net reduction in global GHG for projected increases in meat and milk production are to be developed, a holistic approach such as LCA, should be used to quantify emissions on a per unit product basis."*

Criteria for Selection of Environmental Impact Assessment Methods

The first requirement is to choose an appropriate environmental impact tool. The aim should be to improve the knowledge of impacts associated with the current scale and methods of production. Furthermore, where increased levels of output are contemplated for the target area (as is the case with Food Harvest 2020) the selected environmental tool should be capable of estimating the change in environmental impacts. In some cases the tool (model) may be aimed at quantifying a single impact category, e.g. global warming potential. Some studies will require the model to be more comprehensive with a capability to deal with a wider range of environmental impact categories.

Types of tools

A number of different types of assessment tools have been devised to establish relevant environmental indicators, which can be used to evaluate the environmental impacts of livestock and crop products (Dalgaard, 2007). The environmental assessment tools can be divided into two broad categories, area-based indicators and product-based indicators.

Halberg *et al.* (2005, page 37) suggest that the following distinction should be made with regards to suitability as related to spatial context:

"Indicators linked to environmental objectives with a local or regional geographic target should be area based – while indicators with a global focus should be product-based. It is argued that the choice of indicators should be linked with the definition of the system boundaries, in the sense that area based indicators should include emissions on the farm only, whereas product-based indicators should preferably include emissions from production of farm inputs, as well as the inputs on the actual farm."

Area based indicators have been used for many years by the Agricultural Institute and Teagasc researchers to quantify losses of nutrients by leaching and runoff from agricultural land into ground and surface waters (Ryan et al., n.d.). These nutrient losses are usually quantified on a per-hectare basis e.g. kg NO_3 per ha. In contrast, greenhouse gas emissions associated with food production are more appropriately assessed using product-based environmental impact tools. Climate change is a global rather than a local phenomenon. Greenhouse gas has an effect on climate irrespective of whether the emissions occur in a field in Brazil or on an Irish farm. This point is emphasised succinctly by Casey and Holden (2006, page 7)

"*The consideration of emissions is not limited to the land area of the farm or the geopolitical boundary of Ireland. It encompasses all the estimated emissions associated with the system, wherever they occur.*"

Examples of product-based indicators are: kg $CO_{2\,eq.}$ per kg of beef carcass, kg $CO_{2\,eq.}$ per kg of milk. In addition to the assessment of on-farm-based emissions, product-based indicators can also deal with the emissions emanating from upstream processes involved in the production of inputs (Russell, 2010). Fertilizer manufacture and distribution would be an example. Commercial production of nitrogen fertilizer is no longer carried out in Ireland. Irrespective of where the product is made, the mere fact that nitrogen fertilizer is imported for Irish crop and livestock production means that the environmental burdens associated with the manufacture are attributable to Irish agriculture.

2.2 What are the environmental impact categories to be assessed in this study of the Boyne Catchment?

Global Warming Potential, Eutrophication Potential, Acidification Potential, Land use, Primary Energy Use, Abiotic Resource Use (mineral depletion) and Pesticide Use are environmental impact categories commonly found in the literature. Some research was focused on single impact categories (e.g. Global Warming Potential) whilst other researchers used some or all of the above range. Some of these impact categories are particularly germane to a study of the impact of agricultural production systems in the Boyne Catchment at present. Water quality, for instance, has been impacted by the current levels of production intensity. It is, therefore, appropriate to examine the sustainability of the more intensive production targets set out in Food Harvest 2020.

2.2.1 Global Warming Potential as an impact category

Greenhouse Gas emissions associated with Agriculture and Food Production

In table 2.1, the on-farm emissions are accompanied by emissions from upstream and downstream processes of the food chain. For the purpose of comparison with other research, the downstream activities are not considered in this study of environmental burdens in the Boyne Catchment.

Table 2.1: Emission Sources Associated with Agriculture (Russell, 2011)

UPSTREAM	ON THE FARM		DOWNSTREAM
Many different sources potentially exist upstream and are mainly associated with inputs used on the farm. Some important sources are: Fertilizer production Pesticide and other agrochemical production Feed production (other than feed produced on farm) Extraction and processing of lime. Production of plastics, used for example in mulching, row cover, silage wrap, packaging of chemicals, etc. Production of fuels and electricity Production of machinery, implements and construction materials Transport of raw materials	Mechanical sources Emissions associated with mobile machinery(e.g., tilling, sowing, harvesting and transport vehicles): CO_2, N_2O Emissions associated with stationary machinery (e.g., milling, water pumping, water heating, milking and cooling equipment, etc.,): CO_2, N_2O		Many different emission sources exist downstream. Some important sources are: Product processing and packaging Product transport Product refrigeration Disposal of wastes

Table 2.1 (modified from Russell, 2011) highlights some of the main GHG emission sources associated with agriculture and food production although the list is not exhaustive. Depending on the production system, the relative scale of emissions from each of the three stages in the production chain will vary although, in general, the on-farm emissions tend to be much larger than the upstream or downstream stages. This is particularly evident in the case of ruminant animal production systems.

What is the scale of GHG emissions from Irish livestock production?

It is important to compare the emissions of greenhouse gases associated with different sectors of Irish livestock production. The national values for the year 2008 are presented in Figure 2.1.

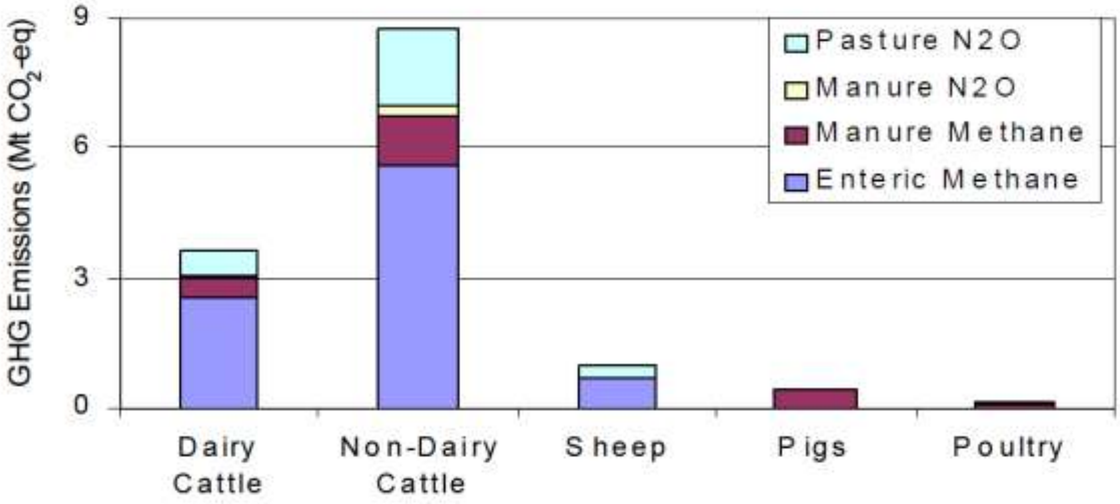


Figure 2.1: Sources of greenhouse gas emissions from livestock production in 2008

Source: McGettigan *et al.*, (2010b)

Figure 2.1 points to the category ‘Non-Dairy Cattle’ as the largest source of GHG production. This category would include the rearing of replacement heifers for the dairy herd but the largest proportion (by far) is associated with beef production. In particular, production of beef from suckler herds is a biologically inefficient process with a large carbon footprint attached (Steinfeld *et al.*, 2006). If binding emission remission targets for the EU non-ETS sector are to be achieved, it is clear that reducing the carbon intensity of beef production becomes a pressing issue. It is also evident that the category ‘Dairy Cattle’ has a relatively low carbon footprint given the large scale of the enterprise. It will become apparent later that the carbon intensity of Irish dairy production is at the lower end of the scale when compared to other European countries (Liep *et al.*, 2010).

As is evident from Figure 2.1, Methane is the dominant greenhouse gas emitted by agriculture (approximately 50% of the total), resulting mainly from enteric fermentation by ruminants and manure management. Quantitatively, the second most important GHG emitted from agriculture is Nitrous Oxide (approximately 38% of total). The reason for such a high proportion of methane is the dominance of grass-based ruminant livestock production and the rather low levels of arable cropping, although cereal and potato production are important in the Boyne catchment area.

Also, from Figure 2.1 it can be seen that the category ‘Sheep’ has a relatively low proportion of total emissions. This reflects the much lower scale and importance of the sheep enterprise which has been in decline for many years, particularly after decoupling of subsidies from numbers produced. Nevertheless, the carbon intensity for sheep i.e. GHG output per kg of lamb, is high.

The pig and poultry enterprises are seen to be relatively insignificant in so far as GHG emissions are concerned. The proposed Food Harvest 2020 increase in output from the pigs sector (50%) is unlikely to be significant from a GHG emissions point of view. However, effects on other impact categories will have to be closely examined.

Methane Emissions (Enteric Fermentation)

Enteric fermentation accounts for about 50% of the GHG, almost all of which is associated with ruminant livestock production (Steinfeld *et al.*, 2006). The 2006 IPCC guidelines (De Klein *et al.*, 2006) give Tier 1 estimates (using default emission factors) of emissions as follows:

Dairy Cows: 117 kg CO_2-equivalent

Other Cattle: 57 kg CO_2-equivalent

Sheep: 8 kg CO_2-equivalent

The first stage process involved in ruminant digestion is known as enteric fermentation. Non-ruminant animals, such as poultry and pigs and pseudo-ruminant horses produce much smaller amounts of methane (De Klein *et al.*, 2006). Improving the productivity of the animal tends to be associated with lower methane emissions per unit of product (de Boer *et al.*, 2011). Examples of improved productivity would be higher yields of milk per cow and faster growth rates in beef cattle. Ruminant production is focused on output in the form of milk, beef or sheep meat per unit of input. In the case of milk production, output productivity can be in the form of high yield of milk (by volume) or moderate volume of milk with high levels of constituents, mainly fat and protein.

Due to the large proportion of total GHG emissions that is represented by enteric fermentation, research is going on to develop cost effective management practices and techniques to reduce ruminant methane emissions per unit of product (Tuomisto *et al.*, 2012). Teagasc has an extensive research programme that includes examination of dietary modifications for ruminants, use of additives or probiotics that reduce CH_4 production and breed selection to focus on higher feed conversion efficiencies. Management strategies that increase the length of the grazing season are being examined, since grazed grass gives rise to lower CH_4 emission than a diet which is mainly grass-silage based (Boyle, 2009). The conflicting requirements of Food Harvest 2020 and the stringent GHG commitments associated with the Energy and Climate Package (EPA, 2010) have added a high degree of urgency to these research efforts.

Methane Emissions (Manure Management)

Manure from housed farm animals is managed in two ways:

1. Farmyard Manure
2. Liquid Manure Systems

Farmyard manure. This is the product produced by animals that are bedded in straw. Being a largely solid material, it is stored in heaps or piles during the winter housing and subsequently spread on land during the growing season. This is associated with low levels of methane (CH_4) production. Handling of farmyard manure, although substantially mechanised, is still somewhat labour intensive. It also requires large amounts of straw, which has to be purchased and transported from the source farms to the livestock farms. On medium and large farms this system of manure management has been largely replaced by liquid manure (slurry) management systems. Stored farmyard manure is associated with significant emission of the potent GHG nitrous oxide (de Boer *et al.*, 2011).

Liquid manure systems. The product, normally referred to as slurry, is stored in tanks or lagoons during the winter housing period for cattle. Within the Boyne Catchment, different counties have different storage (non-spreading) periods. Liquid manure storage is associated with high levels of methane (CH_4) production. When manure is stored or treated as a liquid it decomposes anaerobically and can produce significant quantities of methane. The temperature and the retention time of the storage unit substantially affect the amount of methane produced. Higher temperatures increase the amount of CH_4 produced. The IPCC default emission factors for manure management are graded to reflect different climatic (temperature) regimes (De Klein *et al.*, 2006). Grazing animals deposit manure on fields and subsequent decomposition of the material under mainly aerobic conditions reduces the amount of methane emissions to a low level but under intensive grazing, methane emission is largely replaced by emission of the even more potent greenhouse gas nitrous oxide (N_2O) (de Boer *et al.*, 2011).

Trends in Methane Production

McGettigan *et al*. (2010a, 2010b) examined the trends in methane production from the Irish livestock sector. They found that the reduction in methane emissions from 1998 to 2006 was primarily driven by the reduction in beef cattle and sheep. Sheep derived methane emissions decreased linearly with quantity of sheep-meat produced. However, of considerable importance, they observed that there was a decoupling between cattle derived methane emissions and total beef production. Methane emissions from beef cattle fell by 10% between 1998 and 2006, while beef production dropped by just 3%. A similar trend was evident in the case of dairy production. Dairy-sourced methane emissions fell by 13% between 1990 and 2006 whereas the reduction in milk output was just 3%. The authors contended that this decoupling was mainly driven by improved efficiency of production, specifically reduced finishing times in the beef sector and increased milk production per head in the dairy sector. In view of these non-linear relationships, it seems plausible to suggest that further progress towards efficiency in production of beef and milk would yield reductions in methane emissions and thereby partially offset the effects of intensification associated with Food Harvest 2020. The linear relationship between sheep meat output and methane emissions would seem to be a reflection of the lack of progress towards efficiency in sheep production, in what remains a very traditional enterprise.

Nitrous Oxide (N_2O) Emissions from soils

N_2O emissions take place following the deposition of urine and faecal nitrogen from livestock, the application of chemical and organic nitrogen fertilizers and indirectly from volatilization of ammonia and leached nitrate-N (Flechard *et al.*, 2007). Loss of nitrogen through N_2O is also a feature of arable crop production, and is usually quantitatively lower than in grazing livestock systems (Williams *et al.*, 2006).

Estimates of emissions of N_2O have a high level of uncertainty. There is therefore a a major focus on inventory development for this gas in Ireland and internationally (O'Brien, 2010).

Denitrification is a major biological process that occurs in the production of nitrous oxide (N_2O) – a potent greenhouse gas. Denitrification requires a ready availability of organic Carbon for growth and respiration of the bacteria that mediate the process (Humphreys *et al.*, 2008). Denitrification is, in general, quantitatively higher in grassland than arable soils probably due to higher levels of organic carbon in the former and the disturbance of arable soils associated with tillage practices leading to cumulative oxidation of organic matter.

All additions of nitrogen to soils are likely to be associated with some level of denitrification. At least some gaseous emissions from soil would be of nitrous oxide (N2O). These are estimated by IPCC Tier 1 methodology (IPCC, AR4, 2007). Country specific field results are not yet consistent to move the estimates for Ireland to Tier 2 levels. Enormous temporal and spatial variation is the norm for N_2O emissions. Humphreys *et al.* (2008) estimated that surplus nitrogen is subject to a high level of denitrification (52%) with intensive dairy farming on a clay loam soil. The drumlinized area of the Boyne catchment and all areas with Gley soils would fall into that category. Humphreys' finding is corroborated by results from grazed swards in Northern Ireland. Watson *et al.* (2007a) did a nitrogen balance to account for nitrogen output in product (milk and meat), drain flow, ammonia volatilization and soil nitrogen accumulation. They found that 47 to 56 per cent of surplus N in the system could not be accounted for. They inferred that the loss of N was due to denitrification. The implication is, therefore, that it is desirable to reduce the surplus nitrogen and strive as far as possible for zero nitrogen balance.

Baily et al (2012) quantified the effect of two stocking rates with grazing dairy cows on a clay-loam at Johnstown Castle. The stocking rates and fertilizer treatments were:

1. Intensive grazing: 2.75 LU/ha and N fertilizer at 251 kg N/ha
2. Extensive grazing: 2.07 LU/ha and N fertilizer at 173 kg N/ha

As anticipated, N_2O emissions from the higher stocking rate + high nitrogen were higher than for the extensive stocking rate + moderate N application. The high stocking rate gave rise to pronounced spikes of N_2O in the five days after fertilizer application. The researchers found high spatial and temporal variability in grazed grassland which highlighted the problems of measuring emissions associated with this type of land use. The intensive regime would not comply with the Nitrates Directive and farming at that level of intensity would require derogation from the Directive.

In relation to quantifying emissions of N_2O associated with arable cropping, Teagasc carried out field experimentation on spring barley at Oakpark, Carlow (O'Mara *et al.*, 2007). Some of the available literature indicated that tillage practices could have a significant impact on the pattern of N_2O emissions (Ball and Ritchie, 1999 cited by O'Mara, 2007). It was appropriate to test under Irish conditions what effects, if any, different tillage methods would have under Irish conditions. Two treatments were used; conventional tillage which entailed ploughing followed by the normal pre-planting cultivation and (b) Non inversion tillage, where ploughing did not feature in crop establishment. The results indicated that non inversion tillage (under Irish conditions) did not have any effect on cumulative N_2O emissions, grain yield or soil nitrate. The effects of different nitrogen application rates on N_2O emissions were also examined in the Oakpark experiment (O'Mara *et al.*, 2007).

Reducing Nitrous Oxide emissions

Given the high GHG characterisation factor associated with emissions of N_2O, reduction of its emission from agricultural production would be a desirable environmental objective. Mitigation measures are explored in Chapter 7.

Trends in Nitrous Oxide Emissions

Total N_2O emissions from Irish agriculture in 2008 had decreased by 11% relative to 1990 and by over 20% relative to 1998 peak emissions (McGettigan *et al.*,2010b). It should be noted here that 2008 was the year with the lowest usage of purchased nitrogen fertilizer. It is plausible to speculate that at least some of the fertilizer Nitrogen usage in 1998 was wasteful and damaging to the aquatic environment in addition to the high level of GHG emitted. In recent times, N_2O emissions arising from animal deposition on grassland has followed a similar downward trend to methane emissions, with the principal reduction arising from sheep (38%) and non-dairy cattle (11%). Similarly, reduction in the use of mineral fertilizer resulted in a 28.9% decrease in emissions in the decade from 1998 to 2008.

What is the scale of nitrous oxide emission from Irish livestock production?

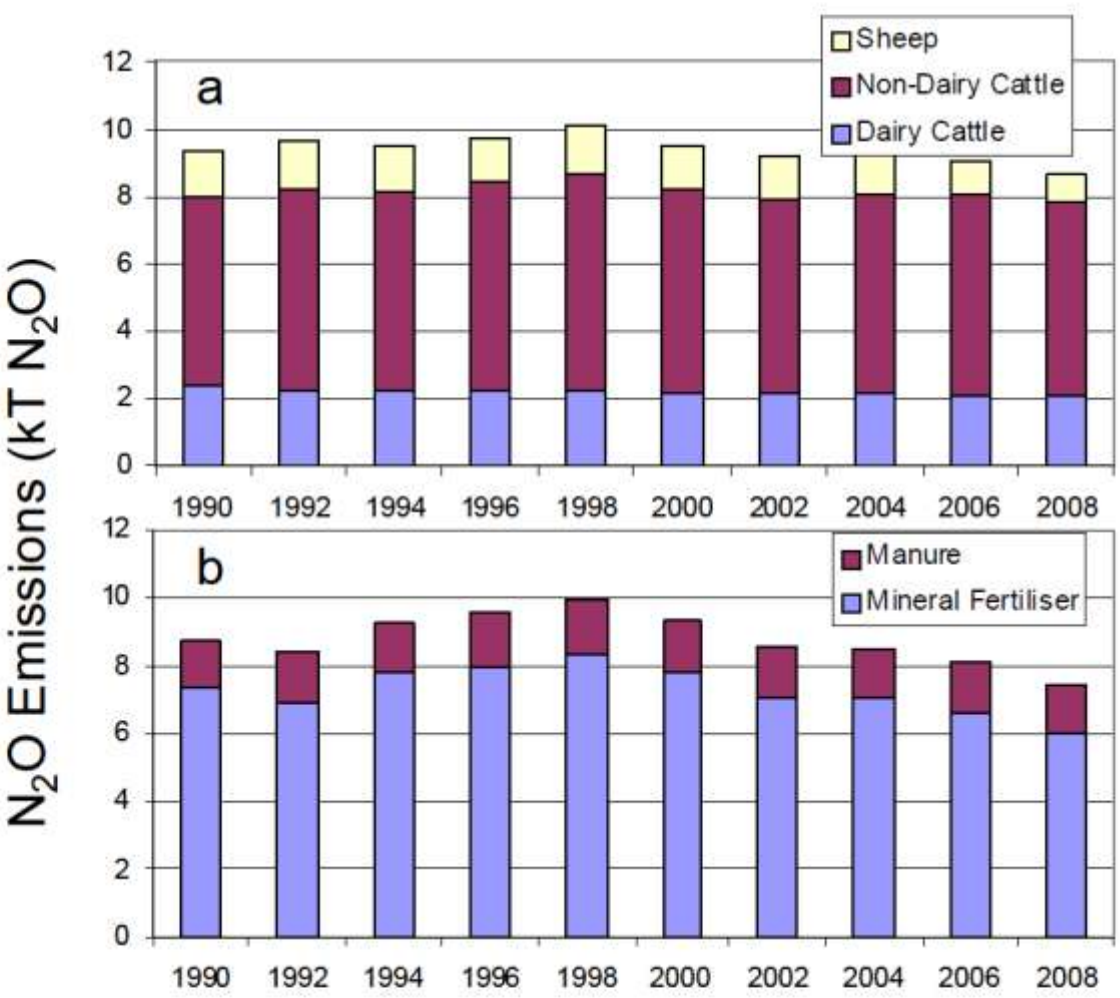


Figure 2.2: Nitrous oxide (N_2O) emissions sourced from a) animal deposition on pasture and b) mineral and organic fertilizer usage between 1990 and 2008.

Source: McGettigan *et al.* (2010b)

Comparative study relating to modelling carbon footprints across the EU27

A study (Leip *et al.*, 2010) was carried by the European Commission's Joint Research Centre to evaluate the livestock sector's contribution to the EU greenhouse gas emissions.

This study (based on 2004 data) compared the carbon footprints from agricultural production in all the EU27 countries. It is a single impact study which focuses only on the climate change issue. Using Life Cycle Assessment methodology in the CAPRI model for estimating GHGs and NH_3, the researchers compared the results with the data from the Greenhouse gas inventories submitted to UNFCCC for the year 2004. The model results provided strong positive evidence of low carbon footprints associated with Irish livestock production systems. According to O'Mara, (Teagasc Website, 2011, page 1)

"This study is particularly important as it is the first time such a range of products have been compared across all EU countries in a single comprehensive study. This will help shape future policy and strategy in relation to the twin goals of food security and climate change."

Ireland and Austria had the lowest carbon footprint in the EU at 1kg $CO_{2\ eq}$ per kg of milk compared with the average for the EU27 of 1.4 kg $CO_{2\ eq.}$ per kg of milk. Pork produced in Ireland has the lowest footprint in the EU27. The carbon footprint for Irish pork (4.8 kg $CO_{2\ eq.}$ per kg of meat) is 64% below the EU average. Irish produced chicken meat also leads the way having a low carbon foot print of 3.3kg $CO_{2\ eq.}$ per kg of meat. The EU average is 4.9. Irish produced beef is ranked fifth lowest in the EU for carbon footprint at 19kg $CO_{2\ eq.}$ per kg of carcass meat. The average footprint for beef produced in EU countries is 22.1 kg $CO_{2\ eq.}$ The study also estimates that Brazilian beef, which is a direct competitor for Irish beef on EU and non-EU markets, has a very high carbon footprint. Where land use change (mainly deforestation) is a factor, Brazilian beef has an enormous footprint of 80 kg $CO_{2\ eq.}$ per kg of carcass. Even where land use change is not considered, Brazilian beef has a very high footprint of 48 kg $CO_{2\ eq.}$ Apart from climate change considerations, land use change (clearing of the rain forest) leading to loss of biodiversity is also an environmental burden associated with some of the Brazilian beef production.

O'Mara (2011, page 1) draws the following conclusion from the study:

" If extra food is needed going forward, Ireland is a great place to produce it because of the low carbon footprint. We are also in good shape with water availability, biodiversity and animal welfare standards. Food and marketing companies should use this to drive export growth, especially in affluent markets that put a premium on environmental and ethical standards."

2.2.2 Energy Use as an environmental impact category

Energy in the Agricultural Sector

The agriculture sector has a multiplicity of energy consuming processes and, firstly, it is important to identify and quantify the environmental burdens associated with each of the key processes and, secondly, to as far as possible build sustainability into energy use.

In the Crop Production sector, fertilizer manufacture, cultivation, harvesting and electricity for grain drying also figure as large users of electricity.

Livestock Production: Operations such as milking cows, cooling milk and heating water are all substantial users of energy.

Care is needed in comparing energy usage in studies emanating from different countries. Life Cycle Assessment of energy as an impact category may give divergent results depending on the fuel mix used in the generation of electricity. In Sweden for example, Sonesson & Davis (2005) cited by Upton (2009) quoted 94% of electrical base load as originating from hydro and nuclear sources. By contrast, approximately 86% of the electricity generated in Ireland is derived from combustion of fossil fuels resulting in the emission of 543g of CO_2 per Kwh (unit) of electricity (Upton, 2009). The effect of this would be to make the environmental impact of electricity-intensive processes (such as milk cooling) much lower in Sweden than in Ireland.

Energy usage on Arable Production Systems

In arable crop production systems, research literature from the UK gives data for energy usage in field operations (Williams *et al.*, 2006). In the cultivation and sowing categories, energy use is dependent on soil type. Chamen and Audsley (1993) cited by Williams (2006) devised relationships to calculate the work rate of operations as a function of the tractor power rating and the soil type. As would be expected, the effect is biggest for cultivation activities, since more work has to be done with soil, while subsequent surface operations like spraying, fertilizer application and combining were largely unaffected. Data on ploughing would indicate that fuel use per hectare is not a function of the size of tractor or implement.

In the explanatory notes accompanying the Cranfield Life Cycle Assessment (LCA) model, Williams *et al.* (2006) refer to a method of environmental impact assessment for energy usage which is categorised as “Primary energy usage”. It is deemed to be a more holistic category than on-farm consumption of energy, particularly when dealing with the upstream activities, such as the production of inputs (diesel fuel for example) for use on farms (Williams *et al.*, 2006).

Energy required for Grain Drying and Storage

Grain harvested in the Boyne Catchment area is usually too high in moisture (typically 20% moisture content, or more) to be stored without treatment. Grain is prone to mould growth if the moisture content is too high. Grain needs to be dried to a moisture level of 14% in dryers. Specific energy requirement for evaporating water in the dryers was estimated to be 4.7 MJ/kg (McLean, 1989, Brookner *et al.*, 1993) cited by Williams(2006). It is then transferred to the grain store and some of it may require air-cooled ventilation with fans to prevent hot spots developing. The average use of energy for cooling is quoted in the literature as 0.3 MJ per tonne (McLean, 1989 and Scotford *et al.*, 1996). The table below uses three sets of long term data to estimate the energy required for safe grain storage.

Table 2.2: Energy requirements for drying crops to achieve stable storage (MJ/tonne)

Years to 2001	Wheat	Barley	Rape	Beans
10 (1st data set)	68	83	101	88
20 (2nd data set)	153	169	280	245
30 (3rd data set)	152	170	257	230

Source: Williams *et al.* (2006)

From Table 2.2 it is clear that cereal grains require the expenditure of less energy than beans and rape to achieve a stable condition for storage.

Energy Requirements on Dairy Farms

Electricity usage on dairy farms has been investigated by Teagasc using short term audits on three farms (Upton, 2009). The objective was to identify if there is scope for reduction of energy usage and hence the “on-farm” carbon footprint. Initial data indicates that reductions in the order of 30-40% may be possible. Upton found that electricity consumption per cow milked ranged from 3.8 Kwh/cow/week to 6.7 Kwh/cow/week. It is not clear what the milk yields per cow of the different herds were at the time the data was collected. The breakdown of energy usage is compiled in the table below

Table 2.3: Energy Data for electricity usage on 3 dairy farms

Item	**% of total**
Milk cooling	32
Lighting	18
Vacuum pumps	19
Water heating	27
Wash pump	1
Milk pump	1
Miscellaneous	3

Source: Teagasc, Moorpark, 2009

Different systems of milk production will have different levels of energy efficiency. Using Life Cycle Analysis (LCA), Cederberg (1998) found that organic production of milk was more energy efficient that conventional production. Conventional production consumed 107.7 MJ per gallon as opposed to the organic system which consumed 91.08 MJ per gallon.

Energy Usage on Pig farms

In 2005 the Carbon Trust UK produced data on energy usage on pig farms in the UK. The results are tabulated (below) for all stages of pig production. The unit of energy is kilowatt-hour (kWh). Two categories were used in the study, Typical and Good Practice.

Table 2.4: Energy usage in each stage of pig production

Production Stage	**Typical per pig produced**	**Good practice per pig produced**
Farrowing	8 kWh	4 kWh
Weaning	9 kWh	3 kWh
Finishing	10 kWh	6 kWh
Feeding system	3 kWh	1 kWh
Manure handling	6 kWh	2 kWh
Total	**36kWh**	**16kWh**

Source: Teagasc, Moorpark, 2009

A 2006 survey by Teagasc of a small sample of pig farms (N=8) found results that were more or less in line with those of the Carbon Trust survey. Average usage was 27 kWh (with a range of 17kWh to 37 kWh) per pig produced. It is clear that there is substantial scope for the least efficient energy users to improve energy efficiency within their production units.

2.2.3 Eutrophication as an environmental impact category

Eutrophication has been described by Toner *et al.* (2005) as Ireland's most serious pollution problem. Eutrophication also has GHG implications so its inclusion or exclusion as an impact category needs to be carefully considered (Harris and Narayanaswamy, 2009). Eutrophication is a term used to describe plant nutrient enrichment in water, in particular nitrogen and phosphorus compounds. As nutrient concentrations increase in water ecosystems, the biomass of algae and other aquatic plants also increases. In lakes, high levels of nutrients can lead to the development of algal blooms and shoreline scums. Fish, especially samonids, may be deprived of adequate oxygen by the respiration of aquatic plants (Toner, 2005). Coarse fish can cope better with eutrophic conditions. The water clarity of some lakes is adversely affected. Antropogenic activities greatly increase the nutrient inputs and exacerbate the water quality problems associated with nutrient enrichment. Mc Garrigle and Champ (1999) remarked on the urgent need for effective management strategies in catchments, measures that could effectively reduce the phosphate load entering rivers. Their observations are particularly relevant in the context of the Water Framework Directive, 2000/60/EC (Council of the European Communities, 2000). This scheme sets out a comprehensive approach to water management and designates large catchment areas as the fundamental unit of management. In the case of the River Boyne, the management unit is called the Eastern Riverboard Management District (ER MD). Water bodies differ in their reaction to increased nutrient input. Shallow lakes that exist in the Kells Blackwater catchment of the Boyne River system are particularly at risk.

Agriculture is estimated to be the origin of 70% of phosporus (P) and 82% of nitrogen (N) in inland rivers and lakes (Toner *et al.*, 2005). Kiely et al (2007) reported that the loss of phosphorus (P) from grassland to surface water was frequently in the order of 2-3 kg P $ha^{-1}yr^{-1}$. More recent results from the Department of Agriculture, Food and the Marine Agricultural Catchments Programme (2013) would indicate lower loss of phosphorus to water, the annual stream exports being in the range 0.12 kg/ha to 0.83 kg/ha of phosphorus. The higher values were associated with the catchments having the highest proportions of heavy soils (Gleys). Using the higher figure, a plausible estimate for the total P input into the waters of the Kells Blackwater Catchment might be 58 tonnes per year from agriculture alone. In addition to that, there would be inputs of P from other sources, namely discharges from municipal waste water treatment plants and licenced waste water discharges from industry.

The ambitious targets set out for increased production of some agricultural products set out in Food Harvest 2020 could result in ecological tipping points being reached for many streams and lakes in the Boyne catchment in terms of the ability to sustain present water quality standards let alone the higher standards prescribed in WFD.

The EU Water Framework Directive (2000/60/EC) came into existence in 2000. The primary objective was to achieve good ecological status for all waters by the year 2015, unless there is an extension or derogation. Good ecological status is determined by a number of criteria. These include: nutrient concentrations, microbial contamination, state of aquatic organisms and end use of the water e.g. drinking water, habitat, game-fishing. Of crucial importance, the directive requires measures that would guarantee sustainable availability of these water resources into the future. The mechanism for achieving **Good** status and preserving good status where it exists already is through the adoption and implementation of the River Board Management Plans (RBMP) for each of the RBDs. For this purpose the Boyne Catchment falls within the Eastern River Basin District (ERBD). The River Basin Management Plan is predicated on analysis of the current condition of water bodies and the significant impacts on water of various forms of human activity. Within the RB management plans, the Nitrates Action Programme is seen as the main measure to address water quality issues directly related to agriculture. Despite the name, Nitrates Directive, the control of phosphorus (P) losses to the aquatic environment is a central plank of the directive. Mandatory measures to curtail nutrient losses are set out in the EC Good Agricultural Practice for Protection of Waters Regulations (S.I. 101 of 2009). The document is comprehensive and sets out in detail multiple requirements to be implemented on farms. These include limitations to stocking rates, closed periods for spreading of organic manures and chemical fertilizer, livestock manure storage capacities. In respect of the latter two, different Counties within the Boyne Catchment will have specific requirements.

Water Quality in the Boyne Catchment

There has been a history of poor water quality in the north western part of the catchment and data relating to the Kells Blackwater and its tributaries (EPA, 2008,2010) confirms that the effects are highly persistent.

River Blackwater (Kells).

This river rises near Bailieborough and enters Lough Ramor at Virginia. It flows from Lough Ramor at the Nine Eyes Bridge, passes to the north of Kells and enters the Boyne at Navan.

The river is in an unsatisfactory condition at the upper reaches near Bailieborough. This is probably due to an IPPC licenced discharge. It remains in poor condition upstream of Killinkere. From Killinkere to Lough Ramor, the status improves to **Good** with reduced phosphorus concentration. This would seem to suggest that, despite the presence of large scale pig and dairy farms along that stretch of river, the nutrient management is of a good standard, with low incidence of point source pollution and low concentrations of nutrients in surface runoff. Downstream from Lough Ramor two stations (Nine Eyes Bridge and Daly's Bridge) indicate unsatisfactory status. This would seem to reflect the chronic hypertrophic nature of the lake itself rather than any recent episodes of point source pollution or diffuse pollution impacting on the river itself (Cavan County Council)

Moynalty River.

The Moynalty River is a major tributary of the River Blackwater. It rises south of Bailieboro and stretches along the Cavan-Meath boundary for a few kilometres. It enters County Meath to the north of the village of Moynalty. It joins up with the Blackwater near Oristown to the south east of Kells. The Moynalty Catchment was designated an Agricultural Special Study area under the Three Rivers Project. The Project's final report classified it as a "High Priority". In fact the report stated that the Upper Moynalty River was (at the time of publication, 2000) the worst tributary in terms of water quality in the whole of the Boyne Catchment.

In the EPA Biological Survey of River Quality (2000) the results of surveying done in September 2000 indicated that none of the sampling stations had satisfactory water quality due to widespread eutrophication. Agricultural diffuse sources, industrial and sewage were given as the suspected causes.

This is a river with a history of poor water quality particularly in the upper reaches (Three Rivers Project). Since there are no known point source discharges to the north of Mullagh (which has a Municipal Waste Water Treatment Plant(MWWTP)) it is assumed that the pollution is diffuse sourced caused by run off from land. Land use in the upper reaches is mainly grassland based enterprises, dairying, beef and sheep. Five pig units are located in the Upper Moynalty area including two Integrated Pollution and Prevention Control (IPPC) licenced units. The lower reaches of the river near the confluence with the Blackwater is dominated by good quality arable land.

The WFD status of the river upstream of the Mullagh and Moynalty villages was classed as “Poor” in 2009, with the target date for achieving “Good” status being 2021.

Yellow River (Kells)

The Yellow River is a tributary of the Blackwater (Kells) and the catchment area is approximately 2500 hectares. The catchment is an area of very good land between Castletown and Wilkinstown. According to Carroll (2002), agricultural land occupies 98% of the catchment with a fairly even divide in land use between grassland and arable (mainly cereals, potatoes, forage maize and oil seed rape). The Yellow River has had a history of poor water quality. It is referred to in the WFD Characterization document (2005) as being in the “at risk” category for diffuse pollution. The catchment was a Three Rivers Project pilot study area. Carroll (2002) found that of the farms in REPS, all of the farmyards were ‘fine in general’. Of the 35 non-REPS farms surveyed, less than 10 were given recommendations for improvements to their farmyards. At the time of audit, no significant pollution control works were planned by any of the farmers surveyed. On follow up it was found that very few of the recommendations were carried out.

EPA Study of Boyne Tributaries

In a study for EPA, Daly and Mills (2006), used a modelling approach allied to flow data for developing a rating scale (1-4) for risk of phosphorus (P) diffuse transport from land to water. In all 84 sub-catchments were examined. Some of the Boyne tributaries were included in that study. The modelling work by Daly and Mills corroborates the previously known high risk status of the Yellow (Blackwater) and Moynalty rivers.

Many of the lakes in the upper catchment are eutrophic.

Lough Ramor.

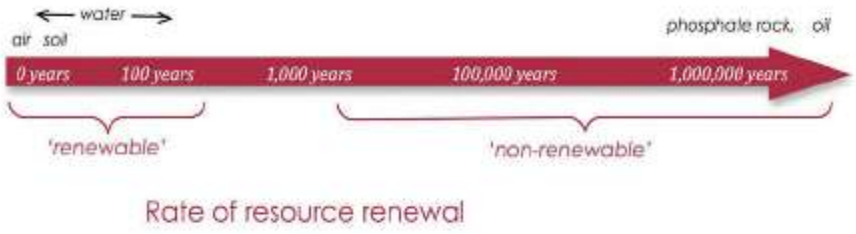
O’Grady (1998) described the “*onset of serious eutrophication problems on Lough Ramor as one of the three major ecological impacts on the Boyne Catchment in recent times”*. It is the largest lake in the Boyne Catchment (800 ha). It is a shallow lake with maximum depth 6 metres and is regarded as a productive coarse fishery. There is a direct discharge to the lake from Virginia Municipal Waste Water Treatment Plant (MWWT). This treatment plant has been upgraded to incorporate phosphate reduction. There is also a large milk processing plant with Integrated Pollution Prevention and Control (IPPC) with licenced discharges to the lake.

The lake has been chronically hypertrophic for decades. The current WFD status is “Bad” with the target date for achieving “Good” status deferred to year 2027 i.e. 12 years behind the general target of 2015.

2.2.4 Abiotic Resource Use as an environmental impact.

Abiotic resources are those that come from non-living materials. Many of the major and minor elements required for plant nutrition fall into this classification. Furthermore, many of the materials concerned are non-renewable. An indicative difference between renewable and non-renewable resources is the temporal scale for renewal. Atmospheric oxygen can be renewed in days or weeks by photosynthesis. Renewal of water as a resource takes somewhat longer and the time scale depends on the rates of processes occurring in the hydrologic cycle. The so called non-renewables, like rock phosphate, generally take millions of years (geologic timescales) to be renewed.

Fig 2.3: Temporal distinction between renewable and non-renewable resources.



Source: Cordell, 2010

Phosphorus: a critical non-renewable resource

Although many of the raw material inputs required in agricultural production are non-renewable, the main focus in this study is on phosphorus since it is of major concern to the future sustainability of agriculture and food production. Phosphorus is a nutrient element (which is a non-renewable resource) that is being consumed at an unsustainably high rate (Cordell and White, 2011). Aside from looming scarcity, profligate use and poor nutrient management of the element phosphorus has been a prime cause of water quality problems in riverine, lacustrine and estuarine ecosystems (Toner, 2005). This damage is evident in parts of the River Boyne catchment especially the sub-catchment of the Kells Blackwater tributary.

Phosphorus in farm animal nutrition

Farm animals require dietary phosphorus for body maintenance and growth. It is an essential element in bone structural development and a number of other physiological processes. Pigs have special requirements. Even though phosphorus is present in feed grains in substantial amounts, the chemical form in which most of it is stored (phytate) is not digestible by the pig's monogastric digestive system because of a lack of the required enzymes (Smith et al., 2003). Hence most of the phytate-P ends up in the slurry and paradoxically the animal's diet has to be supplemented by an available form of P. The digestibility of phytate phosphorus can be increased when a supplementary enzyme phytase is incorporated in the diet (Jacela et al., 2010). This mitigation strategy is discussed further in Chapter 7.

Phosphorus Availability

Phosphorous is the eleventh most abundant element in the lithosphere (Steen, 1998 cited by Cordell, 2010). However, for practical purposes, this is a somewhat misleading statistic. In reality phosphate is a finite non-renewable resource. High grade phosphate ores, especially containing low levels of undesirable contaminants, are being rapidly depleted. Current world consumption of rock phosphate is about 140 million tonnes per annum and most of the reserves/resources are under the control of only a handful of countries.

Geopolitical factors could lead to supply side vulnerability (Cordell, 2010). Five countries account for the bulk of readily available deposits – US, China, Morocco, South Africa and Jordan. The US is rapidly exhausting its high grade reserves and has just become a net importer of phosphate. The US has signed a free trade agreement with Morocco under which it imports high grade phosphate. Its Florida phosphate mine is predicted to be viable for about another 20 years. In 2008, China imposed a 135% tariff on phosphate exports (Cordell, 2010). A plausible scenario, therefore, might be the possibility of a complete ban on P exports from China in a strategic move to safeguard its own food security. Morocco is perceived as a friendly state but much of the phosphate is mined in Western Sahara, an area where security could be fragile. Morocco has occupied Western Sahara since Spain withdrew in 1975. Upward mobility of phosphate price seems a possible scenario as good quality deposits begin to diminish. Price instability with sharp peaks is also a strong possibility. As an example, the rock phosphate commodity price (Morocco) spiked by 800% between January 2007 and September 2008 (Cordell, 2010). It was a serious wake-up call for the international community. Diminishing phosphorus resources had joined the short list of other critical global issues along with climate change, peak oil, diminishing water resources and food security.

The past decade has seen a levelling off of demand for phosphate in parts of the developed western world after years of profligate use. In the Irish situation, Teagasc personnel have expressed concern that soil phosphorus is being run down as grassland farmers have opted to draw on soil P reserves built up over decades. Nevertheless, Cordell (2010) has predicted that, while the global supply of high grade phosphate is likely to be constrained, there is likely to be an increasing future demand.

Phosphate fertilizer for agriculture accounts for roughly 80% of the P used worldwide. The other uses are: detergents (12%), P supplementation of animal feeds (5%), speciality applications (3%) (Jasinski, 2012).

Innovative recycling measures for phosphorus that close the loop to the greatest possible extent, are needed to buy time, to turn around what might be a hard landing into a soft landing (Elser, 2012). A high recovery and reuse rate of all sources of phosphorus may be necessary to meet global demand (Cordell, 2010). Some of the available options for reduction of phosphorus wastage in the food chain will be examined in detail in Chapter 7 (mitigation).

2.2.5 Land Use as an Impact Category (including impact of land use change)

Land use within the catchment has a multiplicity of determinants and constraints. Heavy clay soils are constraining when it comes to arable crop production and are largely devoted to grass-based livestock production. This is particularly so in the drumlin area in the north-west of the catchment. Steeply sloping fields present obvious difficulty for the use of machinery and may, if cultivated, lead to a risk of soil erosion. Farm size is an important determinant in the economic use of land. Dairy farming for instance requires a substantial area of land adjacent to the farmyard, as cows have to be milked twice per day. Small or fragmented holdings are usually devoted to drystock production systems. Different farming systems have different income potentials. Dairying is the most profitable enterprise. Beef and sheep production are heavily dependent on financial incentives from the European Union and national government. Even having due regard to the prevailing constraints, land use frequently comes down to the personal preferences and circumstances of the land owner and his/her immediate family.

In Chapter 1, reference was made to the fact that on balance the achievement of the Food Harvest 2020 targets involves a shift from extensification to intensification as far as land use is concerned. A holistic approach must therefore include land use as an impact category.

Many LCA studies (Williams, *et al.*, 2006; Basset-Mens., 2007; Tuomisto *et al.*, 2009) include land use as an environmental impact category. Williams *et al.* (2006), in a wide ranging LCA study of 10 major land based agricultural commodities, compared organic and conventional methods and found that the land area used for most crops and livestock production would almost double by switching from conventional to organic methods. Using LCA modelling, Tuomisto et al (2009) examined the environmental impact of contrasting farming systems. As well as land use, the impact categories included energy and GHG balances of organic, conventional, and integrated systems. However their main focus was on the opportunity cost of land used in each system. Land is a scarce resource and there are opportunity costs involved in its alternative uses. The project researchers cautioned that in LCA studies, impact results may be misinterpreted if opportunity costs of land use (alternative uses for the land) are not taken into account when comparing intensive and extensive land usage.

Intensive land use and ecosystem services

In addition to food production, land provides for society a range of benefits called ecosystem services. These include the cleaning of local water supplies, sequestration of GHGs and space for wildlife habitats.

In their research modelling, Tuomisto *et al.* (2009) found that using a small part of the farm for energy crop production could have a desirable effect on the climate balance sheet. Although biodiversity impact modelling is beyond the scope of this study, nevertheless the growing of crops for wildlife can be examined in outline. The agri-environmental schemes Rural Environment Protection Scheme (REPS) and the Agricultural Environment Options Scheme (AEOS) provide financial incentives for devoting small areas on farms for the benefit of wildlife welfare. In the Boyne Catchment in 2010, there were 98.46 ha of linnet habitat in situ and linseed was grown on 4.78 ha.

Land Use and Carbon Sequestration/Emission

The build-up of carbon in the soil as organic matter is referred to as carbon sequestration. The quantitatively increasing pools of carbon so formed are known as ‘sinks’. The soils that deliver a net loss of carbon over time are referred to as ‘sources’. Whether a soil is a source or a sink, at any given place and time, depends on the balance of inputs and outputs (Rosenzweig and Hillel, 2000). The input starts off with the uptake of atmospheric carbon dioxide in the process of photosynthesis. Subsequently, there is incorporation into the soil of some proportion of the biomass e.g. the residue of plants and animals. The outputs are dependent on the decomposition of soil organic matter. The type of GHG emitted is governed by the aerobic status of the soil. Under aerobic conditions, the main gas emitted is carbon dioxide – a greenhouse gas. When the system is anaerobic the release of GHG is dominated by methane – a more potent greenhouse gas. Under certain conditions the breakdown of organic matter may be accompanied by the emission of nitrous oxide – an even more potent greenhouse gas.

The opposing processes of carbon sequestration and loss of carbon from soil as GHGs affect atmospheric composition. From the point of view of sustainability, it is highly desirable to use agricultural practices that would retain or increase the level of organic carbon. Rosenzweig and Hillel (2000, page 50) concluded that: *"the preponderance of evidence shows that management of the soil should be aimed at enhancing soil organic matter for the multiple complementary purposes improving soil fertility and soil structure, reducing erosion, and helping mitigate the greenhouse effect."* Farm management systems based on grassland have the potential to sequester substantial amounts of carbon (Jones, 2010). They also counteract the loss of soil mass by erosion.

In addition to management practices, the ability of soils to sequester carbon is governed by the content and type of the clay fraction (Rosenzweig and Hillel, 2000). Soils with a low percentage of clay, e.g. sandy soils, tend to be well aerated, have low adsorptive capacity and retain only low levels of organic matter. In contrast, loams and clayey soils have strong physico-chemical bonds between the clay domains and the macromolecules of humus. The micro-aggregates formed by this process are generally stable and render the organic matter very resistant to oxidation by soil microorganisms. These conditions are favourable for sequestration of carbon.

Carbon Sequestration in managed Irish grassland

Grassland can be divided into two temporal and management categories: temporary and permanent grassland. In Ireland, permanent grassland does include grassland that is rarely if ever renovated (re-seeded). It can however also include land that is reseeded at intervals of five years or more. Whereas, grazing ground can be sustained almost indefinitely with proper management, silage fields usually need to be reseeded every ten years or so due to lack of persistence of perennial ryegrass under cutting regimes, diminishing yields and appearance of invasive species. Temporary grasslands are usually short term leys in a tillage rotation. They serve as a break crop in a cereal rotation. Temporary grasslands are unlikely to be of much consequence as a sink for CO_2.

Extensively managed permanent grasslands have long been associated with low levels of environmental burden across a range of environmental impacts. Soussana et al (2007) have credited this type of management with low use of pesticides, lower inputs of fossil fuels, less soil erosion and crucially it is a sink for Carbon.

Estimates of carbon sequestration in managed grassland can be obtained directly by measuring changes in Carbon stocks. Long term estimates, however, rely almost exclusively on modelling (Jones, 2010). The potential to use the sequestrated carbon in managed grassland as an offset for agricultural GHG emissions is rather dubious. Estimates of Carbon sequestration by grassland under temperate climatic conditions vary over a wide range. Furthermore, Skinner (2008) found that high biomass removal limits carbon sequestration potential of mature temperature pastures. This would reflect the situation in intensively managed Irish grassland (for grazing and silage). According to Skinner, soil C sequestration does not have an unlimited potential to mitigate CO_2 emissions and the benefits probably do not go beyond a 20-25 year timeframe. Periodic ploughing and reseeding would reduce the sequestration potential even further. According to Jones (2010, page 15) "*Due to uncertainty in location of sinks and their activity we currently only have enough information to infer the order of magnitude of soil carbon sequestration rates in temperate grasslands".* This high level of quantitative uncertainty precludes the use of grassland sequestration to verifiably offset some of the greenhouse gas emissions associated with the livestock production sector of Irish agriculture.

Land Use: Arable Crops – usually regarded as a source as opposed to a sink

Methods of Cultivation

Inversion (ploughing)

Ploughing remains the main method of cultivation for arable crops within the catchment for conventional and organic crop production systems. This method of primary cultivation has several advantages. In reality the plough is an essential tool for organic systems of arable production. As herbicides and fungicides are not permitted in organic systems, ploughing leads to good control of weeds and diseases (Williams *et al.*, 2006).

Minimum Tillage

This method is used by a small percentage of farmers in the catchment area for crop establishment. The increasing cost of fuel, metal and labour has prompted some farmers to examine alternatives to ploughing as the primary cultivation method. Minimum tillage means the preparation of seed beds using shallow power harrowing and rolling. Control of weeds requires increased use of herbicides compared with plough based cultivation.

No Tillage

This is not a method currently favoured by many farmers in the catchment. It involves the direct drilling of rows of seeds into narrow slits made with disk coulters. This is followed by rollers to ensure good seed-soil contact. The stubble of the previous crop is not removed so almost inevitably there is an increased use of agrochemicals. In the event that climate change brings drier summers, this method of crop establishment would have significant advantages e.g., much reduced oxidation of soil organic carbon, conservation of soil moisture, reduced use of energy for crop establishment.

2.2.6 Acidification Potential as an environmental impact category

Many processes in agricultural practice have the potential to acidify and damage sensitive ecological systems.

Nitrate as a acidifying influence

As already flagged, Nitrate is of major significance in agricultural systems as a key plant nutrient in crop production and as a source of pollution in surface water and ground water systems. Nitrate also has acidification potential. The effects of high levels of NO_3^- on (a) base cation depletion (b) aluminium mobilization and (c) water acidification are similar to the effects of $SO_4^=$ (Bouwman and van Vuuren, 1999)

Emissions of ammonia as an acidifying influence

Emissions of ammonia are a cause for concern regarding the acidification of soils and waters. The agricultural sector accounts for nearly all of the NH_3 emissions in Ireland.

Grasslands are used for the spreading of nearly all the slurry produced. Emissions from stored slurry tend to be moderate but there is potential for very high levels of ammonia volatilization post-spreading. It is estimated that 16 % of nitrogen in animal waste is lost in this way (EPA website, 2011). Ammonia emissions from animal husbandry arise from both housed and grazing animals. In the case of housed animals, emissions may be divided into those occurring from animal houses and those coming from the subsequent storage and land spreading of animal wastes. However, there is a large emissions variation between the main animal species: cattle, sheep and pigs.

Quantifying Ammonia Emissions

Due to the high level of complexity involved, results are summarized to provide 'average' emission factors per animal for each of the categories and sub-categories and management types. Total ammonia emissions are then scaled by the number of animals in the country (Sensi, 2012).

Mitigation of Ammonia Emissions

There are management strategies that can be employed to significantly lower the loss of nitrogen by ammonia volatilization. These strategies appear under mitigation measures in Chapter 7.

What relevance has acidification for the Boyne Catchment?

Most of the land area of the catchment is at low elevation, so atmospheric concentrations of acidifying pollutants are likely to be low. The bedrock underlying the Westmeath part of the catchment is composed almost entirely of carboniferous limestone. The dominant soil type is Grey Brown Podzolic (Patrickswell Series) of limestone drift origin (Finch, 1977). The structure is well developed and the pH is normally high. Accordingly, the rivers that drain the area (Stonyford R., Deal R., and Athboy-Trimblestown R.) would be expected to have a high buffering capacity. Likewise large areas of Meath are also on limestone bedrock predominantly overlain with Grey Brown Podzolic soil. In a band to the north of Kells and Navan there is a different geology. An area of Silurian shale bedrock is overlain with Acid Brown earth soil type drained by the Kells Blackwater (Finch et al., 1982). Management of this high quality farmland over decades would have involved applications of lime in the form of burned lime and laterally ground limestone. The soils of high pH would therefore impart alkalinity to the surface water bodies. Repeated measurements in the catchment indicate values that are hard alkaline river water, providing sufficient evidence of the sustained buffering capacity of the underlying soils and geology (Casey, 2008). Natural acidification of drainage water outflow from peat bogs would be acid, but would be rapidly neutralized by contact with base material on leaving the bog area. However, one could not rule out acidifying effects beyond the boundary of the catchment from fugitive acid-forming emissions. Whether these depositions are harmful depends on the deposition site.

2.2.7 Pesticide use as environmental impact category

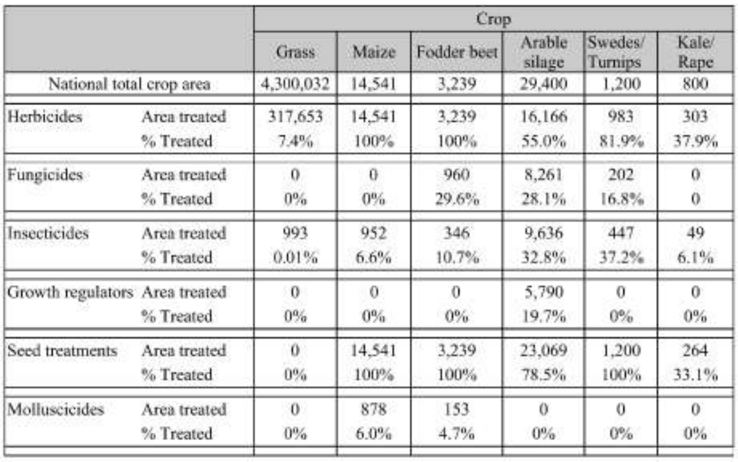
Pesticide is the generic term for a range of chemicals used in agricultural production. In crop production they include insecticides, herbicides, fungicides, moluscicides, growth regulators and seed treatments.

In Ireland, availability of pesticide products (agrochemicals) and their usage is regulated by the Pesticide Control Service of the Department of Agriculture, Food and the Marine. Agricultural pesticides are principally controlled by EU legislation governing the placing of plant protection products on the market (European Council, 1991). The aim of the legislation is to ensure that, through risk assessments, authorised plant protection products do not pose a threat to human and animal health and the wider environment under normal conditions of use.

Pattern of Pesticide use in Irish Agriculture

National surveys of pesticide use in Irish agriculture were carried out in 2003/2004. The results were published for grassland and forage crops (DAFF, 2006a) and for arable crops (DAFF, 2007). The reports were compiled for six categories of plant protection products: herbicides, fungicides, insecticides, molluscides, seed treatments and growth regulators.

Table 2.5: National Pattern of Pesticide Usage



		Crop					
		Grass	Maize	Fodder beet	Arable silage	Swedes/ Turnips	Kale/ Rape
National total crop area		4,300,032	14,541	3,239	29,400	1,200	800
Herbicides	Area treated	317,653	14,541	3,239	16,166	983	303
	% Treated	7.4%	100%	100%	55.0%	81.9%	37.9%
Fungicides	Area treated	0	0	960	8,261	202	0
	% Treated	0%	0%	29.6%	28.1%	16.8%	0
Insecticides	Area treated	993	952	346	9,636	447	49
	% Treated	0.01%	6.6%	10.7%	32.8%	37.2%	6.1%
Growth regulators	Area treated	0	0	0	5,790	0	0
	% Treated	0%	0%	0%	19.7%	0%	0%
Seed treatments	Area treated	0	14,541	3,239	23,069	1,200	264
	% Treated	0%	100%	100%	78.5%	100%	33.1%
Molluscicides	Area treated	0	878	153	0	0	0
	% Treated	0%	6.0%	4.7%	0%	0%	0%

One of the striking results to emerge in the above table was the low level of pesticide usage on grassland farms. Herbicides were used of 7.4 % of the grassland area. In most cases this would be accounted for by the use of specialized sprays for the control of perinneal weeds, particularly the troublesome broad-leaved dock. Renovation of pasture would usually involve the desiccation of the old sward with glyphosate prior to ploughing or reduced cultivation. This would ensure the establishment of a reseeded pasture free from perinneal weeds.

The next chapter, (Chapter 3) sets out a profile of agricultural production in the Boyne Catchment.

Chapter 3

Agricultural Production Profile of the Boyne Catchment

Introduction

The activity data sets for crops and livestock production in the Boyne Catchment were sourced on a confidential basis from the Department of Agriculture, Food and Fisheries. The information was supplied on Excel spreadsheets which facilitated rapid aggregation.

3.1 Cereal Crops in the Boyne Catchment

3.1.1 Barley (Hordeum vulgare)

Belgium leads Ireland in producing the highest yields of Barley in the world. This is probably due to the higher proportion of winter Barley grown in Belgium.

In terms of areas grown in the Boyne Catchment, Barley is second to Wheat but the pattern is different to wheat in that Spring barley is more popular than the Winter varieties. In the baseline period (2007-2009), an average of 7141 hectares of Spring Barley were grown whereas the average for the winter crop amounted to 2162 hectares. The grain from the barley crop is mainly used for animal feed. Grain reaching a specific quality can be used for malting. Malt is a raw material in the brewing and distilling industries. Irish Distillers produce about 380 litres of alcohol from a tonne of Barley. Barley straw is used for animal bedding or, in small amounts, as a fibrous feed in the diet of ruminants. A new market outlet for straw will be as a feedstock for combustion in the biomass power generation plant at Rhode, Co. Offaly. The plant is sufficiently close to the cereal growing areas of the Boyne catchment to keep transport costs at a low level. The projected requirement is 40,000 tonnes per annum equivalent to about 8000 hectares of barley. Where there is not a financially rewarding market outlet for straw, it is sometimes chopped by the harvesting combine and subsequently ploughed in to provide a valuable soil conditioner which builds up the level of organic matter in soil. Winter Barley is usually sown in September and harvested in July of the following year. Spring Barley is sown in April and harvested in September of the same year. Spring Barley requires less expertise and inputs than the winter crop but is lower yielding. Under favourable conditions and good management, winter barley has the potential to yield 10 tonnes per hectare (Spink, 2012). This requires high levels of fertilizer and chemicals to control fungal diseases.

3.1.2 Wheat (Triticum aestivum)

On a world-scale, Wheat is of enormous importance as a human and animal food. Over the last decade, Ireland had the highest Wheat yields in the world (Spink, 2012). The development of improved varieties of Wheat has thus far been dependent on classical breeding techniques. Breeding for yield improvement has in general stagnated in the past decade with progress estimated as 1% increase year on year (Spink, 2012). The projected increase in population would require yield increase in the order of 1.7% per annum to meet demand. There are no GM Wheat varieties grown commercially anywhere in the world although Rothamstead Research has been evaluating a GM wheat which discourages insect pests.

Parts of the Boyne Catchment area have climate and soils very suitable for Wheat and this is reflected in the large areas grown. Winter Wheat is dominant and reflects the much higher yield and profit potential. It is, however, not suitable for bread making and is used exclusively as a so-called “feed Wheat”. Winter Wheat was grown on an average 9363 hectares during the baseline period (2007-2009). Winter Wheat crops were able to withstand the severe winter of 2010-11 and went on to produce near record yields in the harvest of 2011. Spring Wheat, which has a lower yield potential can in some cases reach “milling standard” which means it is suitable for bread making. Spring Wheat was grown on an average 2060 hectares during the baseline period.

3.1.3 Oats (Avena sativa)

Oats are the least popular of the cereal crops grown in the Catchment. During the baseline period, spring Oats amounted to an average 834 hectares. Winter Oats were grown on an average 1050 hectares. The severe weather during the winter of 2010-11 decimated many winter Oat crops and in some cases the crop was written off completely (Doyle, 2011). The area involved was subsequently re-drilled with a spring cereal crop. Oat crop grown by either organic or conventional means has an important high value market outlet as oatmeal breakfast cereal. Oats are also an important feed for the equine industry.

3.2 Other Arable Crops

3.2.1 Forage Maize

In the period 2007-2009, there was an average area of 11,600 hectares of forage maize grown in the catchment by 191 growers. The area per grower ranged from 2 ha to 81 ha. It is often grown as a cash crop by tillage farmers for sale to livestock farms. It is eligible for the EU Area Aid subsidy on land designated for growing cereal crops. It is a very good break crop in a cereal growing rotation. It can thus break the cycle of cereal fungal diseases and also can build up fertility. The maize crop can utilize large quantities of slurry and farmyard manure and it is an extremely efficient way of recycling the nutrients therein. Livestock manures can supply most of the nitrogen required by the maize crop. Applying too much nitrogen delays the crop maturity date and can be more damaging than applying too little. An application of 33t/ha of cattle slurry supplies about 70% of the P and K needed at Soil Index 3 (Crowley, 2008). After spreading the slurry, it should be ploughed in immediately to retain the nitrogen.

The drumlinized area in the north west of the catchment is not suitable for maize because of soil type, elevation and rainfall. Maize is generally unsuited to clay soils but performs well in sandy loams and medium loams. Soil temperature is a critical factor and the Boyne catchment area is climatically marginal for maize. However, the problem of low soil temperature at sowing time can be overcome by an overlay of photodegradable transparent plastic strips which raise the soil temperature at the critical germination and early growth stages (Crowley, 2005). The strips of plastic, laid directly on the ground at the time of sowing, let sunshine through but impede the loss of energy that can arise through the following processes:

1. Long wave radiation.
2. Evaporation of moisture.
3. Conduction to the air.

Whilst this is costly, it allows earlier sowing and more rapid early growth resulting in higher yields of better quality (higher starch content). Late season frosts in the catchment can be a problem for maize. The first killing frost terminates active plant growth and necessitates harvesting and ensiling of the crop as soon as possible thereafter. Ideally, the crop should be harvested while still green i.e. before the first killing frost. Fitzgerald and Murphy (1998) found that delayed harvesting of immature crops for 3 weeks after frost kill in October, due to wet weather and poor ground conditions, significantly lowered the digestibility of maize silage. Their research established that feeding maize silage of that quality to dairy cows significantly reduced performance in terms of milk yield and milk composition.

Experience in the catchment would suggest that south facing slopes give better results than north facing slopes and maize growing should not be contemplated in sites that are above 100 metres elevation. Frost hollows should generally be avoided. Low rainfall levels and an abundance of sunshine are conducive to high yields and high starch levels.

Maize Silage – A high quality feed

Forage maize is suitable for dairy cows and beef cattle. Maize silage has been extensively researched as a feed for dairy cows (Fitzgerald and Murphy, 1998). The findings of the Teagasc research carried out at Moorepark and Johnstown Castle indicated that a half- and-half mix of grass silage and maize silage was optimum for milk production. This practice has been widely adopted on commercial dairy farms. Good quality maize silage fed with grass silage raised forage intake and improved milk yields and also protein content in the milk.

One drawback that maize silage has, from a nutritional point of view, is its low level of protein. This is counteracted by increasing the level of protein in the concentrate ration by about 5 % compared with the level in all-grass silage. This can be done by increasing the level of soya bean meal or other protein balancer in the ration.

Maize Silage as a feed for beef cattle

A detailed University of Reading trial shows that including maize silage in the forage diet of cross-bred heifers and steers (Holstein X Simmental) originating from dairy herds performed better on maize silage than on grass silage (Anon, 2005). Daily liveweight gain was increased by 13% for heifers and by 20% in the case of steers. A study by Teagasc (Troy *et al.*, 2012) found that maize silage in the diet of cattle had no impact on the eating quality of beef.

3.2.2 Field Beans (Vicia faba)

Field beans averaged 190 ha in the catchment during the baseline period.

It is highly desirable to replace some of the imported Soya Bean meal from South America with a good source of home grown protein (Crowley and O'Mahoney, 2005). Soya is a source of high quality protein but it is expensive due to increasing demand from China. If grown on recently deforested land, soya is reported to have a very high carbon footprint allied to loss of biodiversity (Dalgaard, 2007). The environmental impact of South American soya production has been highlighted in numerous reports. More than 40% of the increase in soya-growing area in Argentina involves land use change *'from virgin lands including forests and savannahs, causing losses in biodiversity'* (Pengue, 2006, cited in Dalgaard, 2007). In Brazil the environmental impact is also serious where soya cropping has expanded in a complex interaction with increasing cattle production leading to deforestation (Dross, 2004, cited in Dalgaard, 2007). According to Foley (2011: page 46):

'It is a critical imperative to halt the expansion of agriculture into tropical forests and savannahs. The demise of these ecosystems has far-reaching impacts on the environment, especially through lost biodiversity and increased carbon dioxide (from clearing land). Slowing deforestation would dramatically reduce environmental damage while imposing only minor constraints on global food production. The resulting dip in farm capacity could be offset by reducing the displacement of more productive croplands by urbanization, degradation and abandonment.'

Transportation of the soya meal to Europe adds further to the overall footprint involved.

As a relatively benign crop from an environmental point of view, Field Beans can serve as a suitable, partial replacement for imported soya. They can be grown successfully in the catchment, although further research is needed to optimize the growing methods. Field Bean, also known as Faba Bean, is a nitrogen fixing crop that requires no Nitrogen fertilizer and therefore has a low carbon footprint. If the soil test is at Index 4, it does not require any phosphate and potash (P&K) fertilizer application (Crowley and O'Mahoney, 1994). Beans require a long growing season and should be sown before March if the crop is to reach its yield potential. Although Beans are thought of primarily as a dietary protein source

(25% crude protein), the energy component in the form of starch is at least as good as that of barley or wheat (Crowley and O'Mahoney, 1994). Beans are suitable for all categories of livestock.

3.2.3 Potatoes (Solanum tuberosum)

The Boyne Catchment has been one of the leading areas for growing main crop- potatoes. The average area grown by 80 commercial growers during the baseline period was 1840 hectares. The average annual tonnage produced was approximately 75,000 during the baseline period. The main varieties grown are Rooster and Kerr's Pink. 38% of the total potato area is planted with Rooster and Kerr's Pink accounts for 21%. Other popular varieties are British Queen, Record, Maris Piper, Golden Wonder and Cara. Crop damage from late frosts can be a problem for growers in the Boyne Cachment. Potato crops are major users of water from rainfall and irrigation. In a climate change scenario which predicts an increased possibility of drier summers (Sweeney *et al.*, 2008), the availability of water in the Boyne Catchment to supply the conflicting demands of domestic users, industry and agriculture may become increasingly precarious.

The potato crop faces major plant protection challenges. Spraying with fungicide up to 15 times to control late blight (Phytoptera infestans – the same organism that caused the catastrophic Irish potato famine) is now common practice (Spink and Mullins, 2012). Over the last 10 years there has been emergence of more aggressive strains of Phytoptera infestans showing fungicide resistance to existing products (Spink and Mullins, 2012). It is becoming apparent that the agro-chemical industry is struggling to cope with the problem. Plant breeders have had only limited success in breeding resistant varieties that can stand the test of time. There are no varieties available to commercial growers with complete resistance to late blight. The variety, Cara, which was bred at the Agricultural Institute Research Centre, (Teagasc) Oakpark, has some degree of resistance. Teagasc is running trial at Oakpark on a new GM potato with resistance to late blight, developed from the variety Desiree (Spink and Mullins, 2012) . Desiree is a variety of Dutch origin (1962), popular in the UK but not in Ireland. The development methodology used was cisgenic (intra species gene transfer) rather than the more controversial transgenic (inter-species transfer of genes) technology. The acceptability of GM crops in Ireland does, however, remain in doubt.

3.2.4 Oil Seed Rape (OSR)

Interest in Oil Seed Rape as a crop has increased in the past few years as the financial returns from the crop have progressively increased. The average areas grown in the Boyne Catchment during the baseline period were 995 ha of Spring sown OSR and 197 ha of Winter OSR. OSR can be used as a break crop in a cereal rotation to break disease cycles. The fungal disease Take-all has a serious impact on Wheat yield and grain quality. Yield of a Wheat crop immediately following an oilseed rape crop can be increased by 0.5-1.5 tonnes per hectare (Teagasc, 2012). Average yields of winter oilseed rape in are 4.2 tonnes per hectare. In contrast, the average yield of Spring planted OSR is just 2.2 tonnes per hectare.

Uses of Oilseed Rape

There are a number of diverse types of OSR that can be grown depending on the target market for the processed product. Plant breeders have differentiated OSR cultivars broadly into three categories (Anon, 2012)

HEAR (high erusic acid rape). Varieties in this category are for specialised use such as bio-fuels. They do not have a food component suitable for human or farm animal consumption.

Double-Low Varieties (low erusic acid, low glucosinolates) have a feed component residue suitable for farm animals after the oil has been extracted. The oil content of the seed is typically 43-44%. This is the type of OSR most commonly grown in Ireland.

HO, LL (high oleic acid, low linoleic acid). These varieties are at the high end of the market and destined for human consumption. As a premium product, they are often grown by organic methods. The oil is very stable at high temperatures and is replacing other oilseeds as high-quality cooking oil. The oil is also used in food processing industries.

OSR for Biofuel

Biodiesel derived from OSR has the potential to reduce this country’s dependence on imported oil. Under EU renewable energy policy there is a requirement for blending of biodiesel with mineral diesel. Ireland has certain targets to meet.

3.3 Forestry and Biomass Crops

3.3.1 Forestry Crops

Forestry is the dominant source of raw material for biomass energy with up to 80% comprised of wood. Small logs from first thinning in forest plantations are ideal wood energy material and provide an early financial reward for the grower. Timber residues such as wood chips and sawdust are also valuable wood energy raw material.

The Food Harvest 2020 blueprint document identified REFIT (Renewable Energy Feed in Tariff) as a key driver of renewable energy. According to Magner (2011, page 25) *'The guaranteed price supports, indexed and offered on a 15-year basis for biomass combined heat and power and biomass combustion, including co-firing of biomass in the three peat powered stations is a significant boost and will help underpin the viability of the bioenergy sector and boost confidence for longer term investments.'*

Of major importance for growers of forestry and other biomass crops in the Boyne Catchment is the availability of a ready and growing demand for their produce for co-firing of the electricity generating station at Edenderry. Co-firing of this station is expected to see a steady increase from a current 120,000 tonnes of biomass to 500,000 tonnes by 2020 (Magner, 2011). Eighty per cent is expected to be from forest-based biomass and much of the remainder is likely to be Willow wood chip. Trials with the use of Miscanthus as a feedstock have encountered some technical problems. It is estimated that one third of the total roundwood harvest from forest sources will end up in the wood energy market.

Long term supply of forest-biomass is a concern as the rate of afforestation has dropped from 20,000 ha per annum in the mid-1990s to about 7,000 ha by the baseline period (2007-2009). This latter figure is considered too low for long –term sustainable wood processing and wood energy sectors (Magner, 2011). If both are to survive and prosper, a minimum and sustained planting rate of 15,000 ha per year would be required (Magner, 2011). Another major consideration is the role that forestry plays in climate change mitigation. A COFORD report states that: '*One of the main services provided by forests – climate change mitigation – is strongly dependent on having young age classes to balance out harvest and* *other decreases in carbon stocks. In the Irish context, this entails the need to continue afforestation at 15,000 ha plus levels for the next two decades.'* (Magner, 2011. page73)

3.3.2 Miscanthus X Giganteus

Although not as popular as short rotation willow coppice, Miscanthus is grant aided under the bioenergy scheme.

The following information on Miscanthus is mainly derived from the Miscanthus – Best Practice Guidelines (Teagasc).

Miscanthus is a C4 -cycle plant (similar to maize) and is climatically more suited to lower latitudes than the Boyne valley. It is a perennial rhizome-producing tall stemmy grass of Asian origin. It is used as a biofuel crop capable of producing heat, electricity generation and CHP (combined heat and power). It produces a lignified stem similar to bamboo. Unlike willow, Miscanthus provides a harvestable biomass crop every year after the year of establishment. Crops are usually low yielding for 3-4 years after establishment. Growth potential is dependent on temperature, water holding capacity of soil and rainfall levels. On the best sites, average harvest (excluding the first 3 years) have exceeded 16 dry tonnes per hectare per year (Teagasc). Miscanthus is sterile and so requires expensive vegetative propagation. The crop must, therefore remain productive for several years in order that establishment costs can be recovered (Christian and Riche, 2008). It is believed that Miscanthus can remain productive for 15-20 years (Clifton-Brown et al., 2007), however, there are only a very limited number of experimental observations on longevity and long term productivity under Irish and UK growing conditions (Christian and Riche, 2008). The first air frost in autumn accelerates leaf senescence and migration of nutrients back into the rhizomes. This fact alone would cast doubt on the suitability of the crop for Boyne Catchment area.

The average area of Miscanthus growing in the catchment in the baseline period was just 41 hectares.

3.3.3 Willow Crops

Willow woodchip is regarded as a promising energy source. Willow is a long term perennial crop which can be productive for up to 30 years, although growers may replant after approximately 20 years to avail of genetic improvements. Yields in the order of 10-12 dry tonnes ha^{-1} yr^{-1} could be expected with a 2 or 3 year harvest cycle (McCracken, 2010). In energy terms this yield would give an annual equivalent of 3300-5700 L of oil ha^{-1}. As willow wood chip is generally considered close to carbon neutral, there are potentially considerable savings on greenhouse gas ($CO_{2)}$ emissions. It is estimated that burning 3,300 L of domestic heating oil produces 8,355 kg CO_2 (McCracken, 2010). McCracken reported that from a unit equivalence point of view, wood chip produces 7 kg CO_2 per GJ (Gigajoule) of energy on combustion whereas heating oil produces 79 kg CO_2 per GJ. Another advantage is that woodchip combustion has a lower environmental impact than fossil fuel. The biomass does not contain many of the noxious chemicals like sulphur that can cause environmental problems when combusted. As a perennial crop (25- 30 years), willow plantations have good potential for carbon sequestration. Net sequestration for coppice willow is estimated as being in the order of 0.22 – 0.39t C ha^{-1} yr^{-1}. The overall carbon balance could be improved if ploughing for ground preparation at the crop establishment stage could be dispensed with in favour of a minimum- tillage approach. Research is being carried out into the feasibility of crop establishment by this type of methodology.

The area grown in the Boyne Catchment is still relatively small (75 hectares in 2010). However, a company in the Kells area is promoting the crop as is Bord na Mona, for co-firing of the Edenderry electricity generating station. It is therefore likely that the area will expand if it is financially rewarding for the growers. The returns from the crop would need to be at least comparable to what can be achieved by growing cereals. Willow woodchip has the potential to make a significant contribution to renewable energy targets.

National Renewable Energy Action Plan

Ireland is legally obliged under EU Directive 2009/28 EC to ensure that 16% of total national energy consumption across the electricity, heat and transport sectors is from renewable sources by 2020. In the National Renewable Energy Action Plan, (submitted to the EU in 2010), the means of achieving the 16% target are as follows; 40% of electricity to be obtained from renewable sources, 12% of the heat sector to be from renewables and in the transport sector 10% to be from renewables (SEAI, 2011). At the end of 2010, electricity consumption attributable to renewables was just 14.8%, an indication that attainment of the 40% target set for 2020 is likely to be challenging. On the basis of current electricity and economic growth forecasts (SEAI, 2011), the 40% target will require an installed renewable generating capacity in the region of 4,000MW.

REFIT Renewable Energy Feed-in Tariff

The recent launch of the REFIT 3 scheme is aimed at incentivising investment in biomass technologies. The agricultural sector is capable of making a significant contribution. The target set for REFIT 3 is the addition of 310MW of renewable electricity capacity to the Irish grid. Of this total, 150 MW will be High Efficiency CHP (combined heat and power) using both anaerobic digestion and the thermo-chemical conversion of solid biomass, while 160MW will be reserved for biomass combustion and biomass co-firing. In practice, the REFIT 3 will provide financial incentive for electricity generation by guaranteeing new renewable generation (and biomass co-firing in existing peat plants) a minimum price for electricity exported to the grid over a 15 year period. Biomass crops were not subjected to environmental systems modelling in this study.

3.4 Livestock Production

3.4.1 Dairy Production

Dairy farming is a major enterprise in the Boyne Catchment. There were an average 896 commercial milk producers with 52,228 cows during the baseline period (2007-2009). Very small producers, with 5 cows or less, were excluded as being non-commercial. Average herd size was 58 cows and the trend is upward movement towards larger herds. Processing of milk into dairy products is carried out at two major plants situated at Bailieborough and Virginia. The Virginia plant supplies all of the cream needed for Baileys Cream Liqueur as well as a range of food ingredients. The plants are strategically placed and served with a good network of roads for milk collection from farms. Ready access to the motorway network, M3, M50 and port-tunnel allow for rapid transportation of export-bound products through Dublin Port.

The removal of milk quotas in April 2015 is expected to herald a rapid increase in milk output. In the period from 1973-83 (i.e. after EEC accession) Ireland's dairy products output doubled. The introduction of milk quotas (with severe penalties for over-quota production) by the EEC in 1983 stalled further increases in output until 2007 when a decision was made to end milk quotas by 2015 (Kennedy, 2011). Transitional small increases in quota will add 9% to our base quota in the run up to 2015.

During the period when European production was curtailed by quotas, other countries continued to forge ahead with expansion in the dairy sector. Since 1985, New Zealand, Brazil, Argentina and Chile have had average annual increases of 3 % in milk output. Australia and United States have increased milk production by about 1.5% on average per annum between 1985 and 2011 (Kennedy, 2011).

The reputation for quality of Irish dairy products is very high and the Irish Dairy Board exports products to some 80 countries. The Kerrygold brand has an enviable reputation for quality in many countries and especially in Germany.

The Food Harvest 2020 blueprint document has a target of increasing output of dairy production by 50% (volume) relative to the average of the baseline period (2007-2009) by 2020. There is increasing evidence that farmers are gearing up for higher production already and are only being constrained by the treat of a super-levy. More milk will mean a requirement for more cows and the quantity and quality of heifers coming on stream would suggest that expansion of milk production will be rapid after the cessation of milk quotas in 2015.

How well placed is the Boyne Catchment to deliver the 50% increase in milk output by 2020?

Average herd size would have to grow from 58 cows to about 85 cows. Farm size (or farm fragmentation) might prove to be a constraint for some producers but this could be coped with by growing or purchasing forage maize locally and maintaining nutrient balance by returning the slurry to the land on which the maize was grown. This is an option that dairy farmers in more disadvantaged areas of the country do not have. Much of the utilizable land in the Boyne Catchment is of good quality, at low elevation and for the most part relatively level (with the exception of the drumlin area in the north-west of the catchment).

In the quota-free environment post 2015, it is difficult to estimate how many farms in the Boyne Catchment may convert from beef and sheep to dairy farming. It may be an attractive option for young full-time farmers with good land resources to switch to the more financially rewarding enterprise of dairy farming. The feasibility of a conversion project from drystock to dairy farming has been examined by Glanbia and the Irish Farmers Journal who invested in a 15 year lease on a large farm and set up a unit to milk 300 cows. Results from the project to date show the capacity to service all the borrowed costs of development work, buildings, livestock purchase and land rental.

On the demand side, there is an upward trend in consumption of dairy products worldwide. The population of the world reached 7 billion in 2010 and world milk production now has passed 700 million tonnes per annum (FAO, 2010). The FAO prediction is for world population to reach 9 billion and if the upward trend for increased consumption is to continue, then there would be a requirement for an extra 150 to 200 million tonnes of milk.

3.4.2 Beef Production

The Teagasc National Beef Research Centre is located in the Boyne Catchment (at Grange, Co. Meath) which is appropriate in that beef production is the leading farm enterprise in the catchment. Sources of beef animals include:

Calves from Suckler Cow Herds

Dairy Beef Animals

These are comprised of pure bred Holstein male and crossbred male and female calves from dairy herds

Approximately 60% of dairy cows are bred to dairy sires with a view to increasing the dairy herd by 3% per annum from 2011 (French, 2010). The expectation is that the pure bred Holstein female calves (50%) would be reared to sustain or increase the dairy cow numbers. The other half of the dairy animals bred from dairy sires (male calves) would number approximately 20,000 calves in the Boyne Catchment. In 2011 up to half (10,000) of those calves were exported live and most of the remainder were castrated for finishing as steer beef.

Bull Beef

The alternative production system which could be adopted would be to rear these animals for so-called bull beef. Bulls are more challenging from an animal management point of view, but they are very efficient convertors of feed and produce beef with a much lower carbon footprint than would be obtainable with steer beef (Dawson *et al*., 2009). A new research programme has been set up by Teagasc to devise a blueprint that is technically feasible and financially rewarding to produce bull beef using calves from the dairy herd. The system's low climate change impact would be a significant positive marketing element in the premium markets. Bord Bia's expectation is that by 2020, 50% of the male calves will be finished as bull beef. This would have a desirable impact on the climate balance sheet i.e a lower $CO_{2\ eq.}$ per tonne of beef carcass. The Department of Agriculture compiled results for almost one million head of cattle processed at factories indicate that young bulls achieved far superior grades than steers (Ryan, 2012). On the EUROP beef classification scale for carcass confirmation, almost 40% of young bulls graded U (the second highest grade) compared with just 5% of steers achieving that grade. The young bulls also fared better than steers on fat scores. On a scale of 1 to 4, fat score 2 (a highly desirable rating from a market suitability point of view) was achieved by 42% of young bulls compared with 14% for steers. Less than 4% of the steers were fat score 4 whereas 27% of steers fell into that category. There is, therefore, a clear commercial advantage in changing over from steer beef production to bull beef production.

Dairy Cross-bred Calves (Male and Female)

Dairy farmers would breed some (approximately 40%) of their least productive cows with beef breeds to provide saleable calves of higher value than pure-bred dairy calves. These calves, both male and female would provide valuable raw material for the beef industry. There are approximately 24,000 of these animals bred each year in the Boyne Catchment. Some of the better heifer calves can be reared as in-calf-heifer replacements for cull cows in suckler herds. The male animals and the surplus females are finished as beef.

Suckler Calf Production.

This is a production system of major importance in the Boyne Catchment.   Although it is a system that produces premium quality beef, the economics and biological efficiency of the system leave it highly dependent on EU and Government subsidies to render it financially rewarding for the farmer.

In the Boyne Catchment there were 57,745 suckler cows and 3,319 herd owners in 2011. Average herd size was 17 cows. Typically, a herd of that size would be a part-time occupation for the owner, with a requirement for some gainful employment or other economic activity beyond the farm gate.

A typical commercial suckler herd would entail using cross-bred dams, usually sourced as heifers from dairy herds. These heifers would be the progeny of crossing Holstein-Friesian dairy cows with sires of the main Beef breeds. Crossbred suckler cows display hybrid vigour (heterosis), the ability to manifest superior traits for fertility and viability. A range of other desirable economic traits can also be optimised. The suckler cow is usually crossed with a third breed to produce the suckler calf. The benefits of heterosis in the suckler calf can thereby be manifested to the maximum possible extent.

The Suckler Calf production system has a high Carbon Footprint because in addition to GHGs produced by the calf, the cow has to be supported on a yearly basis, and accordingly, has an additional Carbon Footprint. Thus, from a Carbon Footprint point of view the suckler beef system compares unfavourably with dairy production, where the cow is a dual purpose animal i.e. producing two products –milk as well as beef.

There is a thriving export market for good quality weanling calves from suckler herds in late Autumn. The calves destined for export are maintained on a high plane of nutrition to ensure high daily liveweight gains. The weanling animals which do not make the grade for the export trade are usually finished to slaughter weight on Irish farms at age range 20-24 months.

Cull Cows and Breeding Bulls

Cows from dairy and suckler herds, at the end of their productive life, are culled and fattened for sale to the low quality end of the beef trade. The cow replacement rate on farms is about 15% per annum. The numbers of cull cows available in the Boyne Catchment would be about 16,500 per annum. Breeding bulls are also sold at the end of their productive life, but the numbers would be low.

Summer Grazing System

This is a low intensity system where farmers with grass to utilize during the growing season would purchase cattle in early summer and adjust their stocking rates during the season to suit the variations in the amount of grass available. This system does not cater for the production of hay or silage as the objective would be to have all stock sold on by the end of the grass growing season. No capital investments like winter housing, slurry storage or winter feed storage are required in this system. The system often provides forward stores in the autumn for sale to winter finishers. The system is sometimes not financially rewarding as summer graziers tend to pay too much for their stock at the time of purchase.

It is sometimes regarded as ‘hobby farming’ as it has a low labour input and can be operated in parallel with full-time off-farm employment.

Winter Finishing of Purchased Stores

This is a highly capital intensive production system where cattle are purchased in the early winter and fed indoors on silage and meal. The aim would be to sell the finished cattle to the factory in Spring. A winter finishing system commonly deals with large numbers of cattle. A large investment in housing and machinery is a feature of the system. The amount of money tied up in cattle is invariably substantial. Financially, it is a risky operation as the difference in price per kg of animal between purchase and sale is generally hard to assess accurately.

Bord Bia National Quality Assurance Scheme.

The Bord Bia Beef Quality Assurance Scheme is an integrated scheme involving the farmer and the processor working in partnership to provide the customer with a quality assured product. The scheme describes the essential quality assurance requirements from primary production through processing to final dispatch. The scheme lays down standards to be complied with at each step of the production chain.

Nationally, almost 32,000 beef producers are members of this scheme. Farmers have to reach certain quality standards to reap the financial premiums attached to the Scheme. Recently the Scheme has been amended to encompass Carbon Footprint assessment at individual farm level. In a global context, it is a cutting-edge, green initiative to measure environmental sustainability at individual farm level. As well as greenhouse gas emissions, sustainability will be also assessed under other impact categories such as biodiversity. It is projected that all 32,000 farms in the Bord Bia Scheme will be Carbon Footprint audited. Carbon Footprint assessment at farm level commenced in 2011.

Market Trends for Beef

In the post-millennium years the EU Commission devised measures to deal with chronic over-supply in the European beef market. This entailed a shift away from methods of EU payments (subsidies) based on numbers of livestock reared. In a process called "decoupling", the link between intensity of production and magnitude of payments was severed. Farmers would receive a "Single Farm Payment" based on historical inventories of cattle (the average of 2000, 2001 and 2002). A process called "extensification" was in reality a reduction of output per hectare in the beef sector. A plethora of schemes and measures were designed to deliver extensification. It was also considered at EU level that a shift towards extensification would have the added benefit of reducing environmental impacts associated with intensive agriculture. The EU Agri-Environmental Scheme was introduced in Ireland as The Rural Environment Protection Scheme (Hynes and Murphy, 2002). Farmers received cash grants for following a five year environmental programme. REPS had built in drivers towards extensification. Stringent conditions were laid down for nutrient management. The upper limit for total nitrogen applied to grassland was 250 kg ha^{-1}. Nitrogen from manures could not exceed the figure of 170 kg ha^{-1}. These limits placed on the input of Nitrogen dictated the stocking density that the land could support. The net effects of the Single Farm Payment and other extensification measures were that fewer cattle were carried on Irish farms.

From 2008 onwards a sudden change in the world beef supply situation started to occur. As demand for beef increased, the supply side failed to deliver adequate quantities of product and world beef prices soared. Increasing world population and emergence of a more affluent middle-class in countries like China, heralded a change in dietary patterns toward a more western diet. Beef became more affordable and consumption increased. This heralded a new era where global food security became a pressing issue.

3.4.3 Sheep Production

There were an average of 971 sheep farmers in the Boyne Catchment during the baseline period and the total number of ewes averaged 91,400. The production system is exclusively lowland. Specialised sheep farming is in the minority as most sheep farmers will have cattle and/or arable cropping as well. Mixed grazing of cattle and sheep gives better results than either cattle or sheep on their own. Within lowland sheep farming there are different systems. The most common would be the Mid-Season Lamb production system. This season makes maximum use of grass. Early lamb production is a system geared to have lambs ready for the Easter market and thereby gain a price premium. The higher price is, however, partly offset by higher production costs.

3.4.4 Pig Production

Pig production is a substantial farm enterprise in the upper reaches of the Kells Blackwater Catchment. The location of the units in a vulnerable non-arable area is at variance with the situation in other countries. In Denmark, Brittany and the UK, pig units are often located in arable cropping areas where cereal feed grains (Wheat and Barley) are grown locally (sometimes even on the same farm) and slurry can be recycled back to replace some of the nitrogen and phosphate removed by the harvested grain crops. This type of close linkage is absent in the case of the pig production in the Blackwater Catchment. Feed grains and compounded feeds are imported from arable areas but much of the slurry is spread on grassland adjacent to the pig units. Where the IPPC licencing of new developments or extension of existing units is required by the Environmental Protection Agency (EPA), a detailed nutrient management plan is required which includes mapping of the available slurry spreading areas and determination of the nutrient status on receiving land by means of soil testing. Exporting of slurry to areas outside vulnerable river catchments and preferably on to arable land would be the norm for obtaining an IPPC licence. This entails the transport of slurry over long distances at considerable cost. For a short period in the 1980s slurry transport out of the Lough Sheelin Catchment (part of the Shannon basin) was subsidised. However, this subsidy ceased after two years and pig producers had to fund the transport from their own resources.

Although the number of units in the Boyne Catchment is small (14), the scale of production is very large. These units range in size from 100 sows to 2,500 sows. Intensive rearing of pigs has taken on many of the characteristics of industry, e.g. large scale production, concentration on one product, strong emphasis on labour efficiency and other cost cutting methods (Courtney, 1986). Accordingly, these methods of food production have been referred to as ‘factory farming’. In common with other industries, this type of agricultural activity has a significant potential to cause environmental degradation, particularly in aquatic systems. Other environmental burdens associated with pig production would include greenhouse gas emissions associated with the importation of Soya Bean meal, some of which is grown on recently deforested land in South America. Greenhouse gas emission is a global problem, so the impact is real and quantifiable whether feed grains are grown in the Amazon basin or in Irish fields. The importation of Soya Bean meal also leads to a loss of biodiversity in the country of origin (Steinfield *et al*., 2006 cited by Dalgaard, 2007). Soya Bean meal is a high quality protein needed in pig diets to balance the low protein present in Irish grown Wheat and Barley. At least a portion of the soya in the pig diet could be replaced by Irish grown field beans. The world consumption of pork is increasing but the cost competitiveness of Irish pork in competing with imports to the home market and with large exporting countries like Denmark on export market is of crucial importance. Feed costs per kg of carcass weight in Ireland are higher than those of the main pig meat producing countries within the EU. The average feed costs for Denmark, Holland, France and Germany are about 12c /kg below the Irish costs (Source: InterPig 2010). InterPig also produced recent data to show that Average Sow productivity at 21 pigs per sow per year is significantly lower than in other EU states. A recent animal welfare development also adds a substantial capital cost to Irish pig production (Carroll, 2011). From 1 January 2013, pig producers will have to replace the practice of tethering sows individually in pens or stalls. Pregnant sows must instead be kept in groups. The cost to the Industry in Ireland is in the order of €30 million. There is no grant aid available to cushion the impact of this cost to the industry. An additional welfare requirement is "Environmental Enrichment". This legislation states "*that a pig shall have permanent access to a sufficient quantity of suitable material such as straw, wood, peat or mushroom compost to enable proper investigation and manipulation that does not compromise the health of the pig*" (DAFF, 2012: 21). Fortunately some or all of these materials are readily available within easy reach of the units in the Boyne Catchment area.

Food Harvest 2020 Target for Pig Production

The Food Harvest 2020 blueprint also envisages a substantial increase in output of pig meat by the year 2020. The target is to increase the national pig herd from 150,000 to 200,000 sows with an increase in productivity from 21 pigs per sow to 24 pigs per sow per annum. A pro-rata extension of these targets to the Boyne Catchment would entail enlargement of the pig herd to 10,400 sows producing 218,400 pigs per annum.

The activity data presented in this chapter will be used to assess the baseline resource use and environmental burdens associated with the production of the 10 crops and 4 livestock enterprises mentioned. The assessment will be carried out in Chapter 5 (Crops) and Chapter 6 (Livestock), using the methodology of Environmental Life Cycle Analysis. For the FH2020 scenario, the activity data will be adjusted pro-rata prior to assessment of the consequential environmental impacts associated with Food Harvest 2020.

The next chapter (Chapter 4) deals with methodology for environmental systems analysis of agricultural production and sources of the data required for this study.

Chapter 4

Environmental Systems Analysis of Agricultural Production in the Boyne Catchment: Methodology and Data Sources

4.1 Choice of Method

In Chapter 2, the literature review cited many instances where Life Cycle Assessment (LCA) was used as a systems analysis tool to identify where major resource use and emissions to the environment had occurred. The use of resources and emissions to the environment are collectively called 'environmental burdens'. Environmental impacts are a consequence of particular burdens. For example Nitrogen leaching is a burden, while the consequent eutrophication is an impact. Emissions to the environment are initially quantified by individual chemical species. A number of these are aggregated into environmentally functional groups (impact categories). Resources used are also quantified by impact categories. Impact categories of relevance to this study are described later in the chapter.

LCA in comparison with other environmental indicators

In this section, some strengths and weaknesses of LCA will be examined. LCA will be compared with other environmental indicators. LCA, like systems analysis in general, represents a substantial simplification of reality. A distinction between area-based and product-based indicators was outlined in Chapter 2. A more detailed consideration of this distinction is now appropriate. In the popular press, 'Food miles' and 'Carbon Footprint' are frequently mentioned and at this stage seem to be embedded in public consciousness.

Food miles is a term used to refer to the distance travelled from the farmer to the consumer (Smith *et al*., 2005) and is commonly used as an environmental indicator for food products. An important question to be posed is to what extent reduction in food miles will increase environmental sustainability. Soya bean meal is an important high protein feed ingredient used at a high inclusion rate in European pig production. Danish research looked at the food miles concept when associated with soya bean production in Argentina and subsequent shipping of the product to Europe (Dalgaard, 2007). Although the soya was transported from Argentina to the Netherlands, the contribution to global warming potential (GWP) was higher from the cultivation of the Soya crop (mainly due to nitrous oxide emission) than from the totality of the transport involved (mainly due to carbon dioxide). The difference is explained by the large discrepancy in GWP between the two gases. It is striking that the GWP associated with shipping was about the same as for the lorry transport involved in getting it to the port, despite there being a huge discrepancy in distance (12,082 vs. 500 km). Shipping appears to be a very climate-friendly mode of transporting produce (Ecoinvent Centre, 2004).

'Carbon Footprint' is another commonly used environmental indicator, and is the climate-change-related metric used on beef production farms as part of the Bord Bia Quality Assurance Scheme. Carbon Footprint combines the atmospheric warming effects of carbon dioxide, methane and nitrous oxide (PAS 2050, ISO Technical standard, 2013)

'Food Miles' and 'Carbon Footprint' have one major advantage: as concepts, they are relatively to communicate to people with limited knowledge of the environmental issues involved. The term 'Food Miles' has perceived associations of food being transported long distances in polluting trucks, aircraft or ships, giving the clear impression that, even when more expensive, eating locally produced food is good for the environment. 'Carbon Footprint' has a perceived association with global warming and something that is harmful to the environment and therefore needs to be minimized. Both terms are relatively easy for consumers to visualize and there is a feel good factor associated with purchasing goods that score well on both counts. By contrast, the term 'Life Cycle Assessment' is difficult to visualize and does not necessarily guide the thoughts of consumers to environmental issues. Understanding LCA methodology is not straight forward for people with limited environmental knowledge, not least because LCA usually involves several environmental impact categories each with its own units of measurement. It is inherently complex and, therefore, more difficult for the ordinary person to understand. Moreover, an LCA-based based comparison of two items will often conclude that product X is better than Y in one impact category but worse in another. This rapidly leads to information overload and confusion for the consumer. Most people are likely to comprehend 'food miles' and 'carbon footprint' because of their perceived connection with global warming.

Probably the most important feature of LCA is that it offers the opportunity of assessing simultaneously several types of environmental impacts (eutrophication, global warming, acidification etc.) for a given product. It makes it easier to assess whether mitigation of one type of emission leads to an increase in other types of emission. Agricultural systems are complex entities and there is a real danger of swapping one form of pollution for another if too narrow a range of environmental impacts are examined. Holistic indicators, like LCA, provide the broad perspectives required.

An additional strength of LCA is that the methodology is well developed and has been used for many years. There is ready availability of proprietary (and in some cases free-to-use) software with databases and life cycle impact assessment. The methodology is ISO standardized.

It should not be inferred that area-based indicators are inferior to LCA. They simply have different uses. Area-based indicators and LCA-based indicators can supplement each other in identification of environmental hotspots.

O'Brien *et al.* (2010) expressed a preference for the greater systems accuracy of LCA when compared with IPCC methodology (See Chapter2: Literature Review)

On balance, therefore, LCA is considered an appropriate tool for an environmental systems analysis of agricultural production in the Boyne Catchment.

4.1.1 Introduction to Life Cycle Assessment (LCA)

The procedures for LCA are set out by the International Standards Organisation. They are part of the ISO 14000 environmental management standards (ISO 14044, 2006; ISO 14040, 2006). According to the ISO 14040 and 14044 standards, a Life Cycle Assessment is implemented in four distinct phases as shown in Figure 4.1:

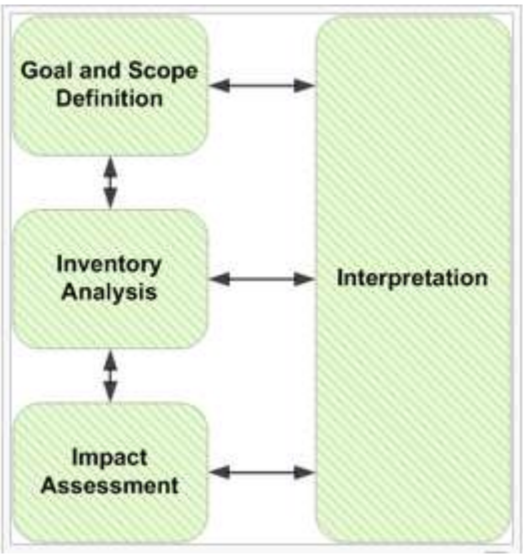


Figure 4.1; Illustration of the phases of and LCA: Source: ISO 1440 (2006)

Goal and Scope Phase

An LCA starts out with an explicit statement of the goal and scope of the study. In the case of the current study, the goal is to examine the sustainability of intensification associated with Food Harvest 2020 by using a model to assess a specified range of environmental burdens pre and post intensification. The goal and scope document include technical details that guide the study:

- The functional unit, which defines what precisely is being studied and provides a reference to which the inputs and outputs can be related. In this study, the functional unit for milk production is 10,000 litres of milk at the farm gate.
- The system boundaries: For example, in this study, the system boundary is cradle-to –farm gate. It encompasses all processes on-farm but also includes upstream processes like fertilizer and feed production.
- Any assumptions and limitations
- The allocation methods used to partition the environmental burdens where there is more than one product. In the case of this study, dairy farming produces two outputs: milk and calves for beef. There are a number of alternative methods for the allocation of burdens.

- The impact categories chosen. In the case of this study, it was decided to use the full range of impact categories available in the model. Accordingly, the chosen categories were: Global Warming Potential, Eutrophication Potential, Primary Energy Use, Acidification Potential, Abiotic Resource Use, Pesticide Use, Land Use. These are described in more detail later.

Life Cycle Inventory (LCI) Phase

This second phase involves the compilation and quantification of inputs and outputs related to all the processes within the systems. Outputs include both material outputs as defined by functional units (e.g. I tonne of carcass beef) and emissions to the environment, e.g nitrate leached. In the case of inputs to agricultural systems, data is available from disparate sources. These inputs include fertilizer, feed and energy.

Life Cycle Impact Assessment (LCIA) Phase

This third phase is essentially based on the life cycle inventory data. First the emissions in the life cycle inventory data are classified, which means that they are assigned to categories according to the type of impact (Dalgaard, 2007). As an example, methane is a greenhouse gas and is therefore assigned to the impact category “Global Warming”. If an emitted substance contributes to more than one impact category, then in the classification it is assigned to all of them. Classification is followed by a process termed characterisation. Each substance is assigned a potential impact in the impact category under study. The potential impact of a substance is benchmarked relative to a dominant factor in the category under consideration. In the case of climate change, the Global Warming Potential benchmark is typically 1 kg of CO_2 emission. See table 4.1 for the characterisation of methane and nitrous oxide. The relative impacts (the characterisation factors of a substance) are then multiplied by the mass of each emission and the resulting impact values are summed for the respective impact category (Dalgaard, 2007). In many LCAs, characterisation concludes the LCIA analysis.

Interpretation

This fourth phase is a systematic technique to identify, quantify, check and evaluate information from the results of the life cycle inventory and/or the life cycle impact assessment. The results from the inventory analysis and impact assessment are summarized during the interpretation phase. As an example, the environmental hot-spots can be revealed in this phase. The outcome of the interpretation phase is a set of conclusions and recommendations for the study – what, if anything, can be done about the burdens that have been revealed. According to ISO 14040:2006, the interpretation should include:

- Identification of significant issues based on the results of LCI and LCIA phases of the LCA
- Evaluation of the study considering completeness, sensitivity and consistency checks
- Conclusions, limitations and recommendations.

Allocation of burdens

As mentioned in the Goal and Scope phase, allocation of burdens is required where there is more than one output product from a system. The need for allocation arises frequently in agricultural production. For example cereal crops provide grain and straw as products. This can be problematic as different researchers (and models) use widely disparate methods of allocation. In ISO 14040 (2006), allocation is described as “partitioning the input or output flows of a process or a product system under study and one or more other product systems”. The ISO goes on to suggest the following approach for handling allocation:

Step 1: Whenever possible, allocation should be avoided by:

a. Dividing the unit process to be allocated into two or more sub-processes.
b. Expanding the product system to include the additional functions related to the co-products.

Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way which reflects the underlying physical relationships between them; i.e. they shall reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

Step 3: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way which reflects other relationships between them.

In a Swedish dairy farming situation producing milk and calves for beef, Cederberg and Standig (2003) examined and analysed four different ways of handling the co-products – surplus calves and meat from the milk production system:

1. No allocation. This means that milk takes the whole environmental burden of the production system.
2. Economic allocation. This was based on average calculations by the Swedish Dairy Association of the annual farm income per dairy cow in which the financial returns from the products are divided as 92% for milk, 6% as meat from the culled cow and 2% for the surplus calf. Clearly, depending on market forces, the proportions would be likely to vary from country to country.
3. Cause-effect physical (biological) allocation. The basis for the “biological allocation” is the fact that there is a causal relationship between the diet of the dairy cow and the ability to produce milk, calves and meat. When calculated according to the Swedish fodder tables for the supply of energy and protein to satisfy the cow’s milk production, maintenance and pregnancy, the allocation works out as 85% for milk and 15 % for meat (cull cows) and surplus calves.
4. System expansion. Allocation is avoided by expanding the milk production system to include the alternative way of producing the co-products i.e. meat and surplus calves. The alternative way of producing calves for meat production is by beef cows (sucklers) producing one calf per cow per year and the alternative way of producing meat from culled dairy cows is a beef production system.

The study by Cederberg and Standig showed that economic allocation between milk and beef favoured the position of the beef co-product. However, the system expansion approach highlighted the environmental benefits of co-producing milk with its co-products of surplus calves and meat. Beef production in combination with milk can be carried out with fewer animals than with the specialist beef cow production system.

In an Irish dairy production study, Casey and Holden (2005) compared three methods of allocation (no allocation, mass allocation and economic allocation). Systems expansion was not possible due to insufficient data.

4.2 Suitability of the Cranfield LCA Systems Model

In order to elucidate the impacts of Food Harvest 2020, it was necessary to carry out a wide ranging environmental systems analysis of agricultural production in the Boyne Catchment.

Following an extensive review of literature (over 30 papers and websites) relating to Life Cycle Analysis (LCA), the Cranfield LCA Systems Model (Williams *et al.*, 2006) was chosen because it best reflected the range of agricultural products emanating from the Boyne Catchment and the desired range of environmental impact categories listed below. The model was developed for England and Wales but, after in-depth evaluation, the author of this study has considered it applicable to the target area – the Boyne Catchment. The availability of good data sets permitted localisation of the model to the Boyne Catchment. It allowed the author to change a number of key management variables from the default values to more accurately reflect the prevailing farm management methods in the catchment area.

Other research projects using the Cranfield LCA Systems Model

During the past 5 years this model has been used in a number of DEFRA funded projects. The following are some examples:

1. De Boer *et al.* (2011) assessed greenhouse gas mitigation in animal production
2. Audsley *et al.* (2009) assessed the effects of changes in UK food consumption on land requirements and GHG emissions
3. Webb *et al.* (2013) compared the environmental footprints of foods imported into the UK with the same foods produced in the UK.
4. Williams *et al.* (2011) assessed the role of greenhouse gas mitigation in the sustainable production of food.

5. In a WWF-UK supported project, Audsley *et al.* (2009) addressed the possible scale of GHG emissons by 2050 and the scope to reduce them

4.2.1 Brief Description of Cranfield LCA Systems Model

The project undertaken by the model developers (Williams et al., 2006) was to construct an environmental systems analysis tool to analyse and compare the environmental impacts of alternative methods of production of major agricultural commodities. A comparison of production methods requires a procedure that provides an objective and systematic calculation of the primary energy, material consumption and environmental burdens associated with the production of each commodity involved in the study. Life Cycle Assessment (LCA) provides such a method and was used.

The objectives of the Cranfield University model development project were:

1. To develop and later release a conceptual model to quantify the environmental burdens and resource use associated with the production of agricultural commodities using the principles of Life Cycle Assessment (LCA).
2. To identify and classify the major production systems in England and Wales for the commodities to be studied.
3. To establish the mass and energy flows for each commodity and other necessary input data for the working LCA model, and ensure that the sources and derivation are clearly identified.
4. To code the LCA model in a package, such as Microsoft Excel, with all the main data readily accessible.
5. To use the LCA model to analyse these production systems and demonstrate that the model could compare production systems and could identify high risk parts of the systems (the so called hot-spots).
6. To publish and publicise the working LCA model.

The model developers customised their own inventory of materials and processes for the project. These were based on a diverse range of data sources together with the EU Harmonisation Study (Audsley, 1997) and the Ecoinvent LCA data sources.

It is necessary to enter some caveats relating to this study:

1. The Cranfield LCA model was designed for England and Wales. Nevertheless, the climatic conditions, geology, soils, hydrology, elevation and systems of agricultural production prevailing in the Boyne Catchment closely resemble those features in some areas of England and Wales. Many of the key input variables could be changed from the defaults to more accurately reflect local conditions in the target area. The use of the model was therefor considered appropriate and justifiable.

2. Models are always a simplification of reality, sometimes even a drastic simplification. In this study no sensitivity or uncertainty analysis has been carried out to analyse the sensitivity of the emissions calculated by the model. The model developers have put forward some typical coefficients of variation. These appear below under "Uncertainty in Modelling".

3. IPCC coefficients are widely used and relied on for calculations of Global Warming Potentials. They are embedded in the model for that purpose. On the other hand, the classification factors for calculating the PO_4-equivalents of eutrophication emissions are less widely used and are based on several assumptions (Plumiers *et al.*, 2000). PO_4-equivalents are used in LCA studies to indicate the gross effect of eutrophication irrespective of the location of the emissions. Eutrophication, however, is an environmental impact with pronounced local effects. All catchments are different and all have different hydrologies. Despite these limitations, the results

presented in the study may be the best presently available and serve the purpose of the study.

4. In relation to suggestions for further research, an economic analysis of the components of this study could be a worthwhile exercise. The methodology of this study could be used to provide a valuable research resource for other areas. The choice of model should receive careful consideration. The Cranfield LCA model may be appropriate in some areas but not in others. The commercially available Simapro model is generic in nature but has been used by a number of agricultural systems modellers.

Uncertainty in Modelling

All scientific measurements and models contain some uncertainty (or error). The Cranfield LCA Model is no exception. Some environmental measurements/estimates are subject to greater uncertainty than others. Greenhouse gas emissions from agricultural systems are particularly challenging from a quantitative perspective. There are very large uncertainties associated with N_2O and enteric CH_4 emissions. As a rough approximation, the model developers have suggested that uncertainty (quantified as the coefficient of variation, i.e. standard deviation divided by the mean) might lie in the region of 30% for NH_3 emissions and possibly greater than 50% for N_2O emissions. According to Williams et al (2006), the errors in national inventories of gaseous emissions are typically about 30%. The errors in a whole farm model (which includes field operations; emissions of ammonia, methane, nitrous oxide and nitrate and soil P balance) were in the range 10% to 34% (Williams *et al.*, 2004b) with most of the emissions errors being about 32%. Fuel use estimates have been shown to be highly variable with a typical coefficient of variation of 40%.

Despite the effects of uncertainty on the absolute accuracy of the Cranfield LCA model, the authors suggest that it is relatively accurate at performing comparative analyses (Williams *et al.*, 2006).

4.2.2 Impact Categories assessed by the Cranfield LCA Systems Model

The main impact categories considered in this project were: Global Warming Potential, Eutrophication Potential, Acidification Potential, Primary Energy, Land use, Abiotic Resource Use and Pesticide Use. The Cranfield model was capable of assessing each of these impacts.

Global Warming Potential (GWP): is an assessment of the extra heat trapped in the atmosphere as a result of greenhouse gas emissions. GWP can be calculated using timescales of 20, 100 and 500 years. For this study the timescale used throughout is 100 years as this is the timescale commonly favoured by regulators and climate modellers. The main agricultural sources of greenhouse gases are nitrous oxide (N_2O) mainly from denitrification in soils, methane (CH_4), mainly from enteric fermentation in ruminants and carbon dioxide (CO_2) mainly from the burning of fossil fuel. GWP_{100} is quantified in terms of CO_2 equivalents (table 4.1)

Table 4.1: Global warning potential (GWP_{100}) factors for major gases using the IPCC (2006) climate change values

Greenhouse Gas	GWP 100 yrs, kg CO_2-equivalent
CO_2	1
CH_4	23
N_2O	296

Source: IPCC AR4, 2006

Eutrophication Potential (EP): is an assessment of potential for damage to the aquatic environment when nutrients (e.g. nitrate and phosphate from manure, slurry and fertilizer) are leached (or run off) from land into rivers and lakes. This can have serious implications for water uses and biodiversity. Eutrophication Potential (EP) is quantified in terms of phosphate equivalents: 1 kg NO_3-N and NH_3-N are equivalent to 0.44 and 0.43 kg PO_4 respectively.

Acidification Potential (AP): is an assessment of potential damage caused when acidifying substances (e.g. ammonia (NH_3) from manure/slurry or sulphur dioxide (SO_2) from fuel combustion) result in a decrease in pH of natural habitats (e.g. lakes) thereby causing a detrimental change in biodiversity. Ammonia contributes to acidification despite being alkaline. Whether deposited or in the atmosphere, it oxidises to nitric acid. Note: Ammonia (NH_3) contributes to a number of impact categories. Efforts to reduce its emission will therefore have wide ranging benefits. Mitigation strategies for reduction of ammonia will be discussed in Chapter 7. Acidification Potential is quantified in terms of SO_2 equivalents. 1 kg NH_3-N is equivalent to 2.3 kg SO_2.

Land Use: Land is a scarce resource and there is always an opportunity cost attached to whatever crop or livestock enterprises are being supported.

Primary Energy Use: This is a measure of energy from primary sources such as crude oil, coal and natural gas. When primary sources are transformed into secondary energy (called energy carriers, like electricity and diesel) there is a loss of energy in the conversion. The dominant agricultural fuels include diesel, electricity and gas. They are quantified in terms of MJ (megajoules).

Abiotic Resource Use: This refers to the use of non-biological, non-renewable resources. The developers of the Cranfield model used an aggregation method for natural resources originating from the Institute of Environmental Sciences (CML) at Leiden University (Williams *et al.*, 2006). Their data put many elements and natural resources on to a common scale that is a reflection of the scarcity of the resources. It was quantified in terms of the mass of the element antimony (Sb), which was an arbitrary choice. Their data included most metals, many minerals and fossil fuels.

Pesticide Use: This refers to a range of biocides used in agricultural production. The unit of measurement in the Cranfield LCA Systems Model is ‘dose-hectare’.

4.3 Sourcing of Data for the Boyne Catchment

As a starting point for this study, good quality data was required for the 10 arable crops and 4 livestock enterprises to be assessed.

4.3.1 Agricultural Activity Data for the Boyne Catchment

A GIS for the Boyne Catchment was sourced within ICARUS, National University of Ireland, Maynooth. The shape files were supplied to DAFF (Department of Agriculture Fisheries and Food) with a view to accessing, in a confidential manner, the activity data (livestock and crops) for each of the 5,764 working farms in the catchment for the baseline period (2007-2009). Data were entered into Excel worksheets and coded to ensure confidentiality. The Cranfield LCA Systems Model was also developed on an Excel platform which ensured compatibility and facilitated speedy numerical analysis. The farms with some of the land outside of the catchment were targeted for adjustment of area. This was done on a percentage basis with crop areas and livestock numbers being adjusted pro-rata.

4.3.2 Teagasc data sources

The National Farm Survey is carried out annually by Teagasc on a selection of farms to access aspects of financial and technical performance. A random, nationally representative sample of between 1,000 and 1,200 farms, depending on the year, is selected in conjunction with the Central Statistics Office (CSO). Each farm is assigned a weighting factor so that the results are representative of the national population of farms. It covers all of the main farm enterprises. The results provided important representative data for inputting into the Cranfield model.

The Teagasc Fertilizer Use Survey 2004-2008 was a very important source of quality data for use in modelling fertilizer nitrogen inputs associated with all of main enterprises of the Boyne Catchment. Additional information on fertilizer usage trends was provided by the National Farm Survey.

Trends in Fertilizer Use

It is instructive to investigate the pattern of fertilizer usage nationally over the last few years. It is assumed that the pattern for the Boyne Catchment is similar to the national pattern. In general the lowest amount of fertilizer was used in 2008, the median year of the three-year baseline period against which progress towards FH2020 is to be measured. It is predicted that the level of intensification needed to deliver the targets of FH2020 will require substantial increases in fertilizer usage from the baseline levels (Donnellan *et al.*, 2012)

In Figure 4.2 below, Teagasc Fertilizer Use Survey data indicate that in the period 2003 to 2008 (the median year of the baseline), reduction of fertilizer usage was more severe on grassland farms than on tillage farms. For example, P usage on grassland farms fell by 55% between 2003 and 2008. In Chapter 5 it will be evident that tillage farmers follow Teagasc fertilizer recommendations fairly closely.

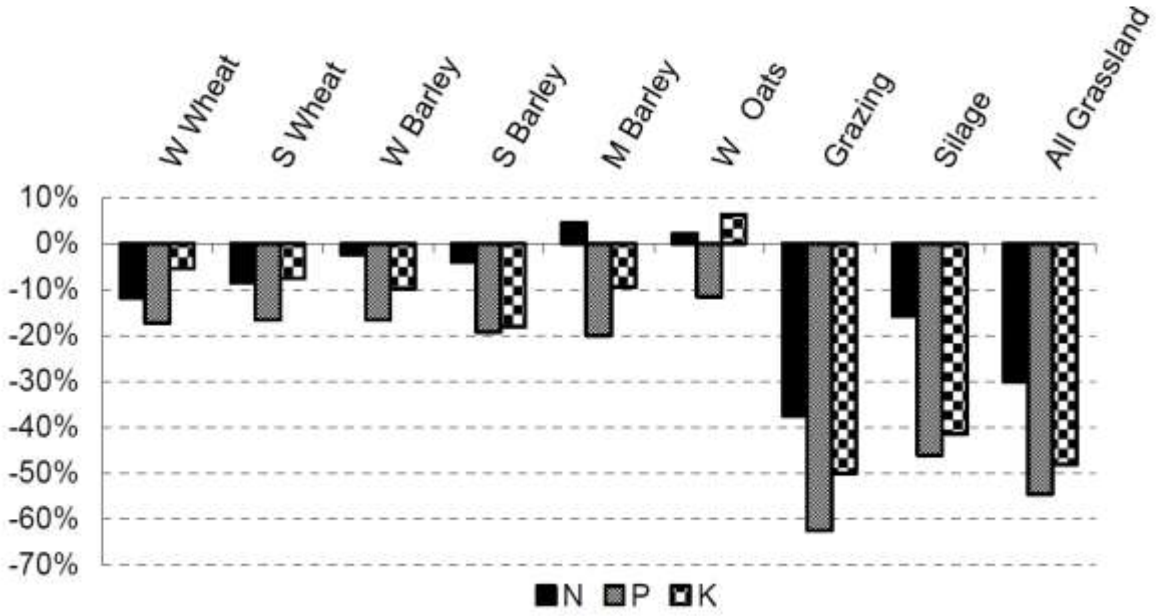


Figure 4.2: Change in fertilizer usage from 2003 to 2008 for cereals and grassland

Source: Teagasc Fertilizer Use Survey

Focusing on nitrogen, in Figure 4.3, it is evident that 2008 was the lowest year for usage across all of the production systems. The decline in usage was most steep in the case of the dairy and the dairy other (mixed livestock) systems. In both of these systems there was a significant upturn in N usage for 2009 and 2010. Across all production systems, usage levels of fertilizer reached the lowest point in 2008. This may have been partly due to an extreme price spike in fertilizers during 2008.

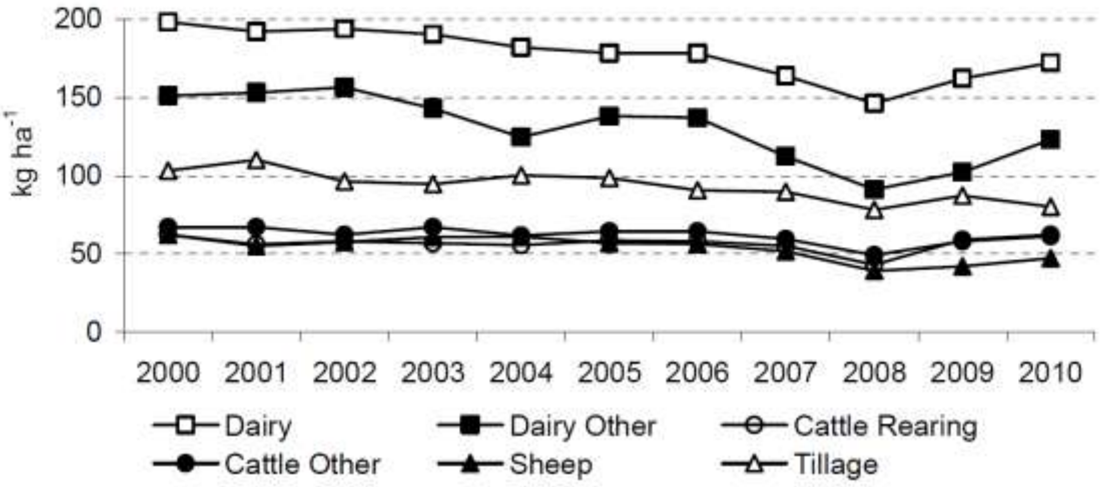


Figure 4.3: Nitrogen application per hectare from 2000 to 2010

Source: Teagasc National Farm Survey

The small decline in nitrogen use for tillage crops during the period 2000-2008 may reflect progress in crop production technologies. This is a factor to be taken into account when modelling crop production in Chapter 5.

Nitrogen Usage and Climate Change Concerns

Projected increase in N fertilizer use associated with FH2020 is a key consideration in relation to greenhouse gas (GHG) emissions. As related earlier, more N usage leads to more N_2O emissions. GHG emission from agriculture in Ireland in 2010 would have fallen were it not for increased nitrogen sales that year as indicated by Figure 4.3, a point noted by the EPA in its presentation of the GHG inventory for 2010 (Duffy et al., 2011). While a GHG constraint has not been set for the agricultural sector, the Irish Government faces a difficulty in how it partitions GHG emissions in the non-Emissions Trading sector (non-ETS). This sector is required to deliver a 20% cut in emissions by 2020. Other components in the non-ETS sector are transport, waste and domestic uses. While emissions from the transport sector have much diminished in recent years, a return to growth in the economy would reverse the trend. Donnellan (2012) predicts a 17% increase in usage of N per hectare of grassland by 2020 relative to the baseline period (2007-2009). Such an increase would have adverse consequences in terms of reducing GHG emissions from the agricultural sector.

Other environmental concerns regarding higher fertilizer use include potential adverse impacts on water quality within the Boyne Catchment and other sensitive catchments. Much of the projected increases in the dairy sector will depend on the ongoing availability of the Nitrates Derogation to allow higher stocking densities and proportionately higher fertilizer applications than would otherwise be permitted. A cessation of the current derogation would require re-evaluation of the dairy target's component of Food Harvest 2020. A key aspect of FH2020 is that the increase in agricultural activity must be achieved in a sustainable manner.

Data on Pig Production

The EPA website was interrogated for Annual Environmental Reports for IPPC registered pig units. The AERs provided some detailed information on registered units for the baseline period (2007-2009).

The Teagasc Pig Herd Performance Reports provided a detailed analysis of the performance of herds that participated in the Teagasc PigSys recording system. The data included in the analysis for the baseline period was from a total of 103 herds with a combined total of 64,000 sows or 42% of the national commercial sow herd. Expert opinion from extension personnel, however, suggested that PigSys provides indicators that are higher than the average for pig units in the catchment area. The international database InterPig provides annual reports with comparative performance data from the main pig producing states of Europe. Accordingly, key performance indicators used in modelling were derived from a synthesis of several sources allied to expert opinions within the industry.

4.3.3 Sources of Data on Water Quality issues

Historical data on water quality within the catchment was available in various reports from the Environmental Protection Agency, Local Authority environmental reports and reports on the Water Framework Directive.

4.3.4 Farmer attitudes to Food Harvest 2020

A nationwide survey of farmer attitudes to the targets of FH2020 has been carried out on behalf of Ulster Bank (Bogue, 2012). A sample of 275 farmers from clients who avail of advisory and consultancy services from private agricultural consultants participated. The results indicate that farmers' expansion plans are in line with Food Harvest 2020. Dairy farmers are planning a 52% in milk output by 2021. Beef producers are planning a 40% increase. Sheep producers are planning a massive 60% output (far in excess of the FH 2020 target of 20%) by 2021. As the survey was nationwide and the sample was small, it may be less than plausible to extend the results to the target area of this study – the Boyne Catchment. Surveys may provide a snapshot in time of farmer sentiment, but in reality, farmers are likely to think long and hard before they embark on any large scale expansion plan on their own farms.

Two of the major dairy co-ops Glanbia and Dairygold have predicted that their suppliers will increase milk output for 2020 by 55% and 63% respectively (Irish Farmers Journal, 2012). These co-ops are currently planning the expansion of processing facilities to cope with the increasing volume of milk. Glanbia has a substantial presence in the Boyne Catchment with a major processing plant situated at Virginia. Lakeland Dairies, also a major player in milk processing, has commissioned a new dryer for milk powder at Bailieborough to cope with the anticipated increase in milk supply. Figures from Central Statistics office (July, 2012) showed that on a national basis butter production rose by 8% and cheese production rose by 4.7% during 2011.

4.3.5 Other Indicators

Teagasc/FAPRI reported in 2008 that a 50% increase in milk production by 2020 was an attainable objective (Irish Farmers Journal, 2008). In a recent more cautious assessment of the dairy industry (Farmers Journal, 2012), Teagasc/FAPRI contended that milk price will be the main determinant of the level of growth in the dairy sector over the next decade and that 20-30% expansion is more likely than the 50% target set out in Food Harvest 2020. The report cites milk price volatility, higher input costs, tighter margins and adverse weather conditions as reasons for a conservative prediction. The report also cites enormous investment costs in plant and equipment at both farm and processing levels. Expansion comes at a cost and milk suppliers will have to decide whether the additional milk volumes are worth the investment and the extra work.

What, if any, are the tangible indicators on the ground of movement towards delivery of the FH2020 targets?

Early indications, on a national basis, of farmers intensifying production or gearing up for higher levels of output from their enterprises are also available (McCarthy, 2012). Although these data are national and not available specifically for the catchment, the results are assumed to extend pro-rata to the target area. The official figures (April 2012) from the Animal Identification and Movement (AIM) Database are strongly indicative that farmers intend to deliver on the bovine targets of for Food Harvest 2020. The April 2012 returns showed that the national cattle herd had increased by 218,718 or 3.4%, over the 12 month period to April 2012. The most convincing indications come from changes in the numbers of young cattle. A breakdown of the figures showed a significant increase in the numbers of young cattle in the national herd. The number of cattle in the category ‘less than 18 months of age’ increased by 331,422 or 12.7%. In the case of breeding stock numbers, the AIM database shows a rebuilding of the national cow herd (dairy and beef) is underway.

4.4 Application of Cranfield Systems Model to Boyne Catchment

As mentioned in Chapter 1, the implementation of the Food Harvest 2020 targets in the Boyne Catchment will require intensification of production, notably in dairying, beef, sheep and pig meat. The research methodology therefore addresses the following key questions:

1. What are the environmental burdens associated with the baseline (2007-2009) levels of production?
2. What are the environmental burdens projected for the levels of output envisaged in the more intensive Food Harvest 2020 plan?
3. What are the environmental impact changes (in each of the categories) associated with the implementation of Food Harvest 2020?

An investigation of the sustainability of this intensification in the catchment required a holistic assessment of resource use and environmental burdens associated with production of the main crops and livestock products. The technique of life cycle assessment (LCA) enables resource use and emissions arising from the various production options to be examined in detail.

In the working model, default values were changed, where required, to more accurately reflect the current balance of production and farm management methods in the Boyne Catchment area. In the case of crop production, differences from the defaults were found in the following:

1. Amount of Nitrogen fertilizer applied.
2. Proportions of different cultivation methods.
3. Proportions of straw incorporated or baled and sold.

The first step is the compilation of a set of tables of data input values for each of the target commodities produced in the catchment. This entails some modification of the tables of default data input values produced by the model developers to more accurately reflect the situation in the target area – Boyne Catchment. The tables are focused on those values that are significantly different at local level from the default values produced by the model developers.

Chapter 5 deals with the environmental consequences of changes to crop production under the Food Harvest 2020 regime.

Chapter 6 deals with the environmental consequences of changes to animal production under the Food Harvest 2020 regime.

Chapter 5

Environmental Burdens of Crop Production in Boyne Catchment

5.1 Implementation of Cranfield model for main crops grown in the Boyne Catchment

Objective: Use of The Cranfield LCA model to provide an assessment of the environmental burdens and resource use for the individual crop enterprises in the catchment and consequently to establish the environmental consequences resulting from changes in crop production under the Food Harvest 2020 regime.

5.1.1 Fertilizer Nitrogen Usage

In view of the nitrogenous emissions to air and water associated with Nitrogen fertilizer application (Williams *et al.*, 2006), one of the key requirements for modelling of each crop is to examine the data available for the use of fertilizer N on crops grown in the target area. Data on the average use of fertilizer N were obtained from the Teagasc Fertilizer Survey 2004-2008. The next step was to compare the Teagasc advice for each crop and the average use of fertilizer N on the farms of the survey in the Mid-East region. Use of averages in Column 4, Table 5.1 was justified to compensate for small sample anomalies in some of the crops being assessed or unavailability of values under some headings. These figures were in turn compared with the default values for each crop used in the Cranfield Systems Model.

Table 5.1: Comparison of Fertilizer N data (Kg N/ha)

Crop	Fertilizer Survey Mid-East	Teagasc advice	Average	Model defaults
Winter wheat	201	203	202	208
Spring wheat	183	141	162	175
Winter barley	183	143	163	154
Spring barley	129	116	122	110
Winter oats	141	126	133	n.a.
Spring oats	75	96	80	n.a.
Forage maize	183	158	170	100
Potatoes		155	-	220
Field beans	No nitrogen	No nitrogen		No nitrogen
Oilseed Rape	n.a.	220		200

For each crop, the default input value for nitrogen was replaced by the average of the survey value and the Teagasc recommendation. The Fertilizer Survey did not record a nitrogen input value for oilseed rape, hence the Teagasc N recommendation was used instead of the default value. It was assumed that OSR acted as a break crop in the rotation and therefore was Index 1 for available soil Nitrogen. The survey sample for potatoes was too small to be usable. Also, in the case of potatoes, the wide discrepancy between the Teagasc N recommendation and the model default value could be plausibly explained by the generally 25% higher yields of main crop potatoes in Britain, partly attributable to irrigation (Williams et al., 2006). The model default value for Nitrogen applied to forage maize is substantially below the Teagasc recommendation and on-farm practice. It is clear that a top up of nitrogen with slurry or farmyard manure is budgeted for. The Teagasc Nitrogen recommendations for cereals are generally close to model default values. The percentage of nitrogen used as urea is also an available input for the model. Urea-N is normally confined to topping up with urea (in liquid form) late in the growth cycle of the crop. It is particularly appropriate where enhancement of grain nitrogen percentage is required to bring Wheat to the milling standard.

5.1.2 Crop Establishment Systems

The Cranfield Systems Model allows the proportions of different tillage systems to be varied.

Different tillage systems are used in the establishment of crops and this is of considerable importance in modelling the environmental burdens and resource uses (e.g. energy) associated with crop production. The systems employed are:

- Plough based tillage
- Min-till (non-inversion tillage)
- Direct drilling (no till)

As far as tillage is concerned, different crops have different requirements. Soil type, rainfall, and energy (diesel) usage are other determinants. The mouldboard plough remains the most popular primary cultivation implement in the Boyne Catchment area. One of the key advantages of a mouldboard plough is that it buries weeds and crop residues. This latter is important in the case of cereal crops in that disease can be carried over from year to year on the stubble residue. Ploughing is often followed by further cultivation using power harrow and drill combinations – the so called one pass system. This is a time saving, energy saving method of crop establishment when soil conditions are favourable. Its use to force a seed-bed in wet clayey soils can do a lot of harm to soil structure. In such difficult conditions more traditional (and less aggressive) methods with unpowered implements like disk and tine harrows would be appropriate but more time consuming.

In the case of potatoes, crop establishment requires deep ploughing and additional secondary operations. Ridging and de-stoning of the soil would normally be employed. These are high energy use operations. Harvesting of potatoes also requires much work to be done on soil, so it also is energy intensive.

In the case of cereal crops, the alternatives used in the Boyne Catchment area are plough-based tillage and non-inversion tillage. It is estimated by extension advisers that for cereal growing in the catchment, more than 90% of the tillage would be plough-based. This would be a significantly different proportion from the Cranfield model default values. In Britain, the proportion of min-till for cereal crop establishment is significantly higher, particularly in the drier areas. Accordingly, in the working model, default values were substituted with values that more accurately reflected the situation in the Boyne Catchment.

5.1.3 Use of Straw

The Cranfield Systems Model allows for proportional changes to be made in straw disposal. Cereal straw can be baled and sold after harvest, if there is a market for it. Alternatively, the straw can be chopped by the combine harvester and subsequently incorporated into the soil as a valuable source of nutrients (P&K) and soil conditioner. Maintaining soil organic matter and chopping straw helps keep the structure friable. The offtake of P and K in cereal crops is given in Table 5.2

Table 5.2: P& K off takes in cereal crops (Kg/ha) per tonne of grain yield

Crop type	Straw Removed		Straw not removed	
	P	K	P	K
Winter wheat/Barley	3.8	9.8	3.4	4.7
Spring wheat/barley	3.8	11.4	3.4	4.7
Oats	3.8	14.4	3.4	4.7

Source: Anon, Teagasc Website

It is clear that the loss of K from soil is considerable when straw is removed and that this offsets some of the monetary value when straw is baled and sold.

The proportion of straw incorporated into the soil is a key variable in the model. The default value is 75% incorporation. This is at variance with the disposal of straw in the target area, where Teagasc extension advisers estimate that 90% of the straw is normally offered for sale. Accordingly, the appropriate adjustment was made. In the case of potatoes, the haulms do not have a readily available commercial use, so 100% incorporation would be the norm. The straw of OSR can be used in domestic boilers but presently 90% incorporation is the norm.

5.1.4 Soil Texture

The Cranfield Systems Model allows for proportional changes to be made in soil texture class. The model uses three broad classes for soil texture: Clay, Loam and Sand. Estimates (providing alternatives to the default) were based on expert opinion and scrutiny of available soil survey data. Four counties have been surveyed at Series Level: Meath (Finch et al., 1982), Westmeath (Finch, 1977), Offaly (Hammond and Brennan, 2003) and Kildare (Conry *et al.*, 1970). Cavan and Louth were not surveyed at the Series Level so the General Soils Map (Gardiner and Radford, 1980) was used instead.

5.1.5 Increase in yield due to technology

In the period from the baseline to year 2020 it is plausible to assume that crop yields would increase by a conservative 5% as a result of technological advances like plant breeding. In scenario testing this value is used as an input to model the impacts for different crops in 2020.

5.2 Modelling of the Major Crops

5.2.1 Winter Barley

The average area of winter barley grown in the catchment during the baseline period was 2162 ha. Due to the profitability of this crop it is assumed that the area grown in 2020 will remain approximately the same.

Input values for modelling the crop are shown in Table 5.2.1.1. Some of the model default values are substituted with more representative values for Barley grown in the catchment area.

Table 5.2.1.1: Input Values for modelling Winter Barley

Input Values	Default values	Average Values for 2007-2009	Values for 2020
Cultivation Methods	% by area	% by area	% by area
Plough based	57%	90%	90%
Reduced tillage	41%	8%	8%
Direct drilling	2%	2%	2%
Varietal changes and soil			
Increased yield from technology	0%	0%	5%
Proportion clay soil used	21.7%	22%	22%
Fertilization			
Nitrogen (kg-N/ha)	150	150	150
Proportion of N as urea (%)	18%	12%	12%
Straw Incorporation			
Proportion of straw incorporated	15%	20%	20%

Most barley straw is baled and used for bedding and roughage in a totally mixed ruminant diet. An emerging market for baled straw is co-firing for electricity generation. Unsuitable weather at harvest time may render it necessary to chop the straw for incorporation (ploughing in) as a soil conditioner and source of nutrients, especially Potassium (K).

Table 5.2.1.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	**Default values**	**Average values for 2007-2009**	**2020 values**
Primary energy used MJ t^{-1}	2,437	2,429	2,363
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	415	420	412

Eutrophic Pot. [kg PO_4 equiv] t^{-1}	2.5	2.5	2.3
Acidification Pot. [kg SO_2 equiv] t^{-1}	2.1	1.8	1.8
Pesticides dose-ha t^{-1}	0.8	0.7	0.7
Abiotic resource use [kg Sb] t^{-1}	1.4	1.4	1.4
Land use grade 3a ha t^{-1} *	0.16	0.159	0.152
Nitrogen losses			
NO_3-N kg t^{-1} to water	3.2	3.3	3.2
N_2O-N kg t^{-1} to air	0.5	0.5	0.5
NH_3-N kg t^{-1} to air	0.8	0.6	0.6
N_2-N kg t^{-1} to air	6.5	6.7	6.3
Other Emissions			
CO_2 (total) to air kg t^{-1}	149.6	149.2	145.1
CH_4 to air kg t^{-1}	0.2	0.2	0.2
PO_4-P to water kg t^{-1}	0.2	0.2	0.2
K to water kg t^{-1}	0.3	0.3	0.3

* Land use grade 3a is described as good quality agricultural land. It is land capable of producing moderate to high yields of a narrow range of arable crops, especially cereals, or moderate yields of a wide range of crops including cereals, grass, oilseed rape, potatoes and the less demanding horticultural crops (Agricultural Land Classification of England and Wales, MAFF, 1988). This is very representative of the arable areas of the Boyne Catchment.

Global Warming Potential remained relatively unchanged across the different scenarios. Primary energy estimated for the baseline period remained constant relative to the defaults. However its value was slightly reduced by 2020. Eutrophication Potential remained constant for the baseline period relative to the default. However it was reduced for the 2020 scenario. Abiotic resource use remained static across all scenarios. Pesticide was reduced slightly from the default but remained static across the baseline and 2020 scenarios. In Table 5.2.1.2 the disaggregation of 'Nitrogen Losses' and 'Other Emissions' into individual chemical species helps to identify hotspot components. This pattern will be repeated for all crops.

Nitrogen losses

Nitrate losses to water were substantial and were consistent with Agricultural Institute and Teagasc findings over many years of research (Kiely, 2007; Ryan et al., n.d.). However the value remained relatively static across all scenarios.

Nitrous oxide values remained unchanged across all scenarios. Whilst the values are numerically small, they are, nevertheless, of major significance from the climate change perspective because of the high GWP of N_2O i.e. 296 kg CO_2–equivalent. Ammonia values were lower than the model default value. They did, however, remain constant between the baseline period and 2020 scenarios. N_2 gas returned to the atmosphere represented a completion of the nitrogen cycle and was benign from a climate change perspective. However, where this was due to denitrification it represented a loss of plant-available nutrients.

Other Emissions

Total CO_2 emitted to air remained relatively static across the 3 scenarios. Emission of methane to air remained constant at a low level that was relatively insignificant compared with values that pertain in ruminant animal production. Phosphate emission to water remained constant throughout and was not out of line with Teagasc findings over many years (Kiely et al., 2007; Ryan et al., n.d.). As previously indicated, phosphate transfer from land to water has a major role in the eutrophication of rivers and lakes. Whilst emission of the plant nutrient potassium (K) to surface water has no significant impact on water quality (Toner, 2006), it does represent a loss of a key plant nutrient, which must be replaced by fertilizer derived from rock potash, a non-renewable resource. This also requires expenditure of energy but on a lower scale than nitrogenous fertilizer manufacture.

Table 5.2.1.3: Relative proportions of GHG burdens for Winter Barley in the baseline period

GHG	**Emission level (kg t^{-1} fresh weight)**	**GWP**	**Total burden Kg CO_2-equiv.**	**Total burden %**
N_2O	0.5	296	148.0	49%
CH_4	0.2	25	5.0	1.5
CO_2	149.2	1	149.2	49.5%

Total			302.2	100%

N_2O and CO_2 account for almost all of the GHG burden

Table 5.2.1.4: Relative proportions of GHG burdens for Winter Barley in year 2020

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.5	296	148.0	50%
CH_4	0.2	25	5.0	2%
CO_2	141.7	1	141.7	48%
Total			294.7	100%

The model developers used IPCC emissions factors for N_2O, CH_4 and CO_2 emissions [IPCC Guidelines, 2006]. The disaggregation of GHG emissions into individual chemical species helps to identify hotspots in the system. This method of quantification will be repeated for all other crops.

As the above tables show, the differences between average for the baseline period and the 2020 scenario are rather small. Although nitrous oxide emission appears quantitatively small, its high GWP ensures that its contribution to GHG burden is substantial – approximately 50% of the total. CO_2 emission is also a significant contributor but CH_4 emission is insignificant. As will be seen later CH_4 emissions are a major GHG issue in animal production – ruminant production systems in particular.

Table 5.2.1.5: Primary energy usage proportions associated with winter barley crop

Proportion	**Default**	**Average for 2007-2009**	**Year 2020**
Field work: Cultivation	24%	25%	24%
Field work: Spraying	3%	3%	3%
Field work: Fertilizer application	3%	3%	3%
Field work: Harvesting	10%	10%	10%
Crop storage & drying or cooling	6%	6%	6%
Pesticide manufacture	7%	7%	7%
Fertilizer manufacture	47%	47%	47%
Total	100%	100%	100%

All field as proportion of total	40%	41%	40%
Field work: proportion as diesel	70%	70%	70%
Field work: proportion as machinery manufacture	30%	30%	30%

This disaggregation helps to identify activities giving rise to major use of primary energy ("hotspots"). The proportions of primary energy use for the winter barley crop remain constant across default, baseline and 2020 scenarios. Fertilizer manufacture accounts for nearly half of the primary energy (47%) followed by cultivation (25%) and harvesting (10%).

Output of Crop product

In table 5.2.1.6 the total tonnage of the winter barley crop (grain + straw) is quantified per hectare and for the whole catchment on a dry-matter basis. Primary crop means barley grain. Secondary crop means barley straw.

Table 5.2.1.6: Crop outputs of winter barley

Crop outputs (dry matter)	**Model default**	**Average for 2007-2009**	**Year 2020**
DM yield primary crop t/ha	5.4 t	5.4 t	5.7 t
DM yield secondary crop t/ha	2.0 t	1.9 t	1.9 t
DM total t/ha	7.4 t	7.3 t	7.5 t
DM for entire crop area (2162 ha)	15,999 t.	15,783 t.	16,215 t
Output standardised @ 14% moisture	18,239 t.	17,970 t.	18485 t.

Change in catchment output (@ 14% moisture content) from baseline average to 2020 = + 515 tonnes

Table 5.2.1.7: LCA results aggregated for Winter Barley

Impact Category	**Average values for 2007-2009**	**Year 2020 values (FH2020)**	**Change**
Primary energy	43649 GJ.	43680 GJ.	+ 31 GJ.
GWP (100 yrs)	7,547.4 t. CO_2-e	7,615.8 t. CO_2-e	+ 68.4 t. CO_2-e
Eutrophic Pot.	44.9 t. PO_4-e	42.5 t. PO_4-e	- 2.4 t. CO_2-e
Acidification Pot.	32.3 t. SO_2-e	33.2 t. SO_2-e	+ 0.9 t. SO_2-e
Pesticide Use	12579 dose-ha	12940 dose-ha	+ 361 dose-ha
Abiotic Resource Use	25.2 t. Sb-e	25.9 t. Sb-e	+ 0.7 t. Sb-e
Land Use	2857 ha.	2809 ha.	-48 ha.

Changes in environmental burdens associated with FH2020 are relatively small for this crop.

5.2.2 Spring Barley

The average area of spring Barley grown in the catchment in the baseline period was 7141 ha. Spring barley is a low-input low-output system of relatively low profitability.

Table 5.2.2.1: Input Values for modelling Spring Barley

Input Values	Default values	Average for 2007-2009	Values for 2020
Cultivation Methods	% by area	% by area	% by area
Plough based	57%	95%	80%
Reduced tillage	41%	3%	18%
Direct drilling	2%	2%	2%
Varietal changes and soil			
Increased yield from technology	0%	0%	5%
Proportion clay soil used	9%	9%	9%
Fertilization			
Nitrogen (kg-N/ha)	110	122	116
Proportion of N as urea (%)	8%	5%	8%
Straw Incorporation			
Proportion of straw incorporated	0%	0%	0%

In the input table, it is assumed that all of the secondary crop (straw) is baled and subsequently sold. This would, however, be highly dependent on weather conditions post-harvest. Failure to get dry weather in the few days after harvest would require that the straw be incorporated. There is also an assumption of a gradual shift to higher usage of non-inversion tillage for crop establishment.

Output values from modelling of Spring Barley are given in Table 5.2.2.2 below

Table 5.2.2.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	Default values	Average for 2007-2009	2020 values
Primary energy used MJ t^{-1}	2,281	2,303	2,233
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	375	395	379
Eutrophic Pot. [kg PO_4 equiv] t^{-1}	2.6	2.9	2.7
Acidification Pot. [kg SO_2 equiv] t^{-1}	1.4	1.3	1.4
Pesticides dose-ha t^{-1}	0.3	0.3	0.3

Abiotic resource use [kg Sb] t^{-1}	1.4	1.4	1.4
Land use grade 3a ha t^{-1}	0.182	0.187	0.171
Nitrogen losses			
NO_3-N kg t^{-1} to water	3.6	4.3	3.8
N_2O-N kg t^{-1} to air	0.5	0.5	0.5
NH_3-N kg t^{-1} to air	0.5	0.4	0.5
N_2-N kg t^{-1} to air	3.9	4.1	3.8
Other Emissions			
CO_2 (total) to air kg t^{-1}	141.0	141.7	137.6
CH_4 to air kg t^{-1}	0.2	0.2	0.2
PO_4-P to water kg t^{-1}	0.3	0.3	0.2
K to water kg t^{-1}	0.3	0.3	0.3

Note: Land use grade 3a is used for this analysis of spring barley.

The increased average primary energy use in the baseline period as opposed to the default values is a reflection of a greater use of plough-based tillage. Ploughing is an energy intensive operation requiring the movement of approximately 3,000 tonnes of soil per hectare. In the 2020 scenario, there is an increased proportion of non-inversion tillage and a corresponding reduction in the primary energy use. The change in average yield per hectare from baseline to 2020 could, in part, be explained by the assumption in the model input of an approximate 5% increase in yield due to technology change, principally enhanced genetic progress. The static figures for N_2O emission could be explained by the narrow range of fertilizer N usage across all scenarios (default, baseline and 2020). CH_4 emissions to air were no different to the figures for Winter Barley. Potassium (K) emissions to water were the same as for Winter Barley. Phosphate emissions to water were higher relative to the figures for Winter Barley. This might plausibly be accounted for by the erosion of soil particles in the absence of ground cover across the winter months.

GHG Emissions Burdens: Comparison between baseline average and 2020

Table 5.2.2.3: Relative Proportions of GHG burdens for Spring Barley for baseline average

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.5	296	148	50%
CH_4	0.2	25	5	2%

CO_2	141.7	1	141.7	48%
Total			294.7	100%

Here again the dominant GHG burdens are N_2O and CO_2 with the proportions remaining almost the same as for Winter Barley

Table 5.2.2.4: Relative Proportions of GHG burdens for Spring Barley for year 2020

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.5	296	148	51%
CH_4	0.2	25	5	2%
CO_2	137.6	1	137.6	47%
Total			290.6	100%

Here again, the model developers used IPCC Tier 1 methodology for GHG emissions calculation based on the 2006 Guidelines.

Primary energy use proportions, computed by the model, are shown in Table 5.2.2.5

Table 5.2.2.5: Primary energy usage proportions associated with spring barley crop

Proportion	Default	Average for 2007 - 2009	Year 2020
Field work: Cultivation	29%	28%	28%
Field work: Spraying	3%	2%	2%
Field work: Fertilizer application	4%	4%	4%
Field work: Harvesting	12%	12%	12%
Crop storage & drying or cooling	6%	6%	6%
Pesticide manufacture	4%	3%	3%
Fertilizer manufacture	43%	45%	45%
Total	100%	100%	100%
All field work as proportion of total	47%	45%	45%
Field work: proportion as diesel	70%	70%	70%
Field work: proportion as machinery manufacture	30%	30%	30%

Here again, the disaggregation helps to identify those activities that give rise to major use of primary energy. In the case of Spring Barley, fertilizer manufacture remains a high proportion of total primary energy usage. Primary energy use in cultivation is higher per tonne than in the case of Winter Barley. Since the cultivations are largely identical for both crops, this discrepancy may be a reflection of the lower yield potential of the spring crop compared with the winter crop. Primary energy in harvesting is also higher for the spring crop. This may result from more difficult harvesting conditions that prevail in September than in July when the winter crop would be harvested. Higher moisture conditions and perhaps lodged or tangled crops would be far more likely when the harvesting is in late September.

In table 5.2.2.6 the total tonnage of the spring barley crop (grain + straw) is quantified per hectare and for the whole catchment on a dry-matter basis. The spring barley area for 2020 is assumed to be the same as for the baseline period.

Table 5.2.2.6: Crop outputs of spring barley

Crop outputs (dry matter)	Model default	Average for 2007-2009	Year 2020
DM yield primary crop (grain) t/ha	4.7	4.8	5.0
DM yield secondary crop (straw) t/ha	2.4	2.4	2.4
DM total t/ha	7.1	7.2	7.4
DM for entire crop area (7141 ha)	50701 t.	51415 t.	52159 t.
Output standardised at 14% moisture	57799 t.	58613 t.	59461 t.

The increase in output per ha in 2020 may be attributable to an approximate 5% yield increase due to technology in the input assumptions.

Table 5.2.2.7: LCA results aggregated for Spring Barley

Impact Category	Average values for 2007-2009	Year 2020 values (FH2020)	Change
Primary energy	134,986 GJ.	132,776 GJ.	-2,201 GJ.
GWP (100 yrs)	23152 t. CO_2-e	22536 t. CO_2-e	-1616 t. CO_2-e
Eutrophic Pot.	170 t. PO_4-e	161 t. PO_4-e	-9 t. PO_4-e
Acidification Pot.	16 t. SO_2-e	17 t. SO_2-e	+1 t. SO_2-e
Pesticide Use	17584 dose-ha	17838 dose-ha	+254 dose-ha
Abiotic Resource Use	82 t. Sb-e	83 t. Sb-e	+1 t. Sb-e
Land Use	10961 ha.	10168 ha.	+793 ha.

Primary energy usage, GWP and Eutrophication Potential are reduced for the FH2020 scenario. This is probably due to use of more efficient use of resources by newer cultivars.

5.2.3 Winter Wheat

The tillage areas of the Boyne Catchment are particularly suited to growing Winter Wheat. The average area grown in the baseline period was 9363 ha. It is assumed that the area of high yielding profitable crop will remain approximately the same from baseline to 2020.

Table 5.2.3.1: Input values for modelling Winter Wheat

Input Values	Default values	Average for 2007-2009	Values for 2020
Cultivation Methods	% by area	% by area	%age by area
Plough based	57%	90%	80%
Reduced tillage	41%	8%	18%
Direct drilling	2%	2%	2%
Varietal changes and soil			
Increased yield from technology	0%	0%	5%
Proportion clay soil used	33.7%	34%	34%
Fertilization			
Nitrogen (kg-N/ha)	192	202	195
Proportion of N as urea (%)	18%	18%	18%
Straw Incorporation			
Proportion of straw incorporated	75%	20%	20%

Winter Wheat has a better tolerance of heavier soils than barley. However, heavy soils in drumlin areas are not suitable, in particular, because of the slopes. The assumption for the proportion of clay soils (Gleys) used in the table for Winter Wheat is based on expert opinion and examination of available soil surveys of the catchment from the sources cited above. The use of non-inversion tillage for this crop, in the catchment, is much lower than the default. Nevertheless, there is an assumption that the proportion will increase between baseline and 2020. Straw from Winter Wheat is less valuable than for other cereals. Nevertheless, it is useful as a bedding material for livestock. Accordingly, the assumption for proportion of straw incorporation is set at 20% for baseline and 2020.

Table 5.2.3.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	Default values	Average for 2007-2009	2020 values
Primary energy used MJ t^{-1}	2,325	2,338	2,248
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	458	441	424

Eutrophic Pot. [kg PO_4 equiv] t^{-1}	2.9	2.9	2.7
Acidification Pot. [kg SO_2 equiv] t^{-1}	2.2	2.2	2.1
Pesticides dose-ha t^{-1}	0.8	0.7	0.7
Abiotic resource use [kg Sb] t^{-1}	1.4	1.4	1.4
Land use grade 3a ha t^{-1} *	0.130	0.128	0.123
Nitrogen losses			
NO_3-N kg t^{-1} to water	4.4	4.5	4.1
N_2O-N kg t^{-1} to air	0.6	0.6	0.6
NH_3-N kg t^{-1} to air	0.8	0.8	0.8
N_2-N kg t^{-1} to air	6.9	5.7	5.2
Other Emissions			
CO_2 (total) to air kg t^{-1}	140.7	141.3	135.9
CH_4 to air kg t^{-1}	0.2	0.2	0.2
PO_4-P to water kg t^{-1}	0.2	0.2	0.2
K to water kg t^{-1}	0.3	0.2	0.2

Table 5.2.3.3: Relative Proportions of GHG burdens from Winter Wheat for baseline period

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.6	296	177.6	55%
CH_4	0.2	25	5.0	1.5%
CO_2	141.3	1	141.3	43.5%
Total			323.9	100%

The proportion of GHG as N_2O is slighter higher for the Winter Wheat crop than for either Spring Barley of Winter Barley.

Table 5.2.3.4: Relative Proportions of GHG burdens from Winter Wheat for year 2020

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.6	296	177.6	56%
CH_4	0.2	25	5.0	1.5%
CO_2	135.9	1	135.9	42.5%
Total			318.5	100

The model developers used the IPCC 2006 guidelines for calculation of GHG emissions.

Table 5.2.3.5: Primary energy usage proportions associated with Winter Wheat crop

Proportion	Default	Average for 2007-2009	Year 2020
Field work: Cultivation	21%	22%	22%
Field work: Spraying	4%	3%	3%
Field work: Fertilizer application	3%	3%	3%
Field work: Harvesting	9%	9%	9%
Crop storage & drying or cooling	6%	5%	6%
Pesticide manufacture	7%	7%	7%
Fertilizer manufacture	51%	51%	51%
Total	100%	100%	100%
All field work as proportion of total	36%	37%	36%
Field work: proportion as diesel	70%	70%	70%
Field work: proportion as machinery manufacture	30%	30%	30%

Winter Wheat requires high use of N fertilizer. This is reflected in the fact that more than half of the total energy usage is associated with fertilizer manufacture.

Table 5.2.3.6: Crop outputs of Winter Wheat

Crop outputs (dry matter)	Model default	Average for 2007-2009	Year 2020
DM yield primary crop (grain) t/ha	6.6	6.7	7.0
DM yield secondary crop (straw) t/ha	0.9	2.9	2.8
DM total t/ha	7.5	9.6	9.8
DM (WW) for entire crop area (9363 ha)	70,222 t.	89,884 t.	91,757 t.
Output standardised at 14% moisture	80,053 t.	102,468 t.	104603 t.

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Table 5.2.3.7: LCA Results aggregated for Winter Wheat

Impact Category	Average values for 2007-2009	Year 2020 values (FH 2020)	Change
Primary energy	239570 GJ.	235148 GJ.	-4422 GJ.
GWP (100 yrs)	45188 t. CO_2-e	44351 t. CO_2-e	-853 t. CO_2-e
Eutrophic Pot.	297 t. PO_4-e	282 t. PO_4-e	-15 t. PO_4-e
Acidification Pot.	225 t. SO_2-e	220 t. SO_2-e	-5t. SO_2-e
Pesticide Use	71727 dose-ha	73222 dose-ha	+1495 dose-ha
Abiotic Resource Use	143 t. Sb-e	146t. Sb-e	+3 t. Sb-e

Land Use	13115 ha.	12866 ha.	-249 ha.

Here again the FH2020 scenario is associated with slight reductions in primary energy use, GWP and Eutrophication Potential.

5.2.4 Spring Wheat

The average area of Spring Wheat grown in the catchment during the baseline period was 2060 ha. It has lower yield potential than Winter Wheat. Spring Wheat can potentially reach milling quality (for bread making) if weather conditions at harvest are good. Milling quality wheat normally attracts a price premium over feed wheat.

Table 5.2.4.1: Input values for Spring Wheat

Input Values	Default values	Average for 2007-2009	Values for 2020
Cultivation Methods	% by area	% by area	% by area
Plough based	57%	90%	80%
Reduced tillage	41%	8%	18%
Direct drilling	2%	2%	2%
Varietal changes and soil			
Increased yield from technology	0%	0%	5%
Proportion clay soil used	33.7%	34%	34%
Fertilization			
Nitrogen (kg-N/ha)	208	162	162
Proportion of N as urea (%)	20%	20%	20%
Straw Incorporation			
Proportion of straw incorporated	20%	20%	20%

Table 5.2.4.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	Default values	Average for 2007-2009	2020 values
Primary energy used MJ t^{-1}	2,519	2,397	2,331
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	510	430	424
Eutrophic Pot. [kg PO_4 equiv] t^{-1}	2.9	2.3	2.2
Acidification Pot. [kg SO_2 equiv] t^{-1}	2.5	2.2	2.2
Pesticides dose-ha t^{-1}	0.8	0.8	0.8
Abiotic resource use [kg Sb] t^{-1}	1.5	1.4	1.4
*Land use grade 3a ha t^{-1} **	0.143	0.155	0.147
Nitrogen losses			
NO_3-N kg t^{-1} to water	4.3	3.0	2.8
N_2O-N kg t^{-1} to air	0.7	0.6	0.6
NH_3-N kg t^{-1} to air	1.0	0.8	0.8
N_2-N kg t^{-1} to air	7.0	3.8	3.7
Other Emissions			
CO_2 (total) to air kg t^{-1}	151.8	146.1	141.9
CH_4 to air kg t^{-1}	0.2	0.2	0.2
PO_4-P to water kg t^{-1}	0.2	0.2	.2
K to water kg t^{-1}	0.3	0.3	0.3

Table 5.2.4.3: Relative Proportions of GHG burdens from Spring Wheat for baseline period

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.6	296	177.6	54%
CH_4	0.2	25	5.0	1.5%
CO_2	146.1	1	146.1	44.5%
Total			328.7	100%

Table 5.2.4.4: Relative Proportions of GHG burdens from Spring Wheat for year 2020

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.6	296	177.6	55%
CH_4	0.2	25	5.0	1.5%
CO_2	141.9	1	141.9	43.5%
Total			324.5	100%

The model developers used IPCC Tier 1 methodology (2006 Guidelines) for calculation of GHG emissions.

Table 5.2.4.5: Primary energy usage proportions associated with Spring Wheat crop

Proportion	Default	Average for 2007-2009	Year 2020
Field work: Cultivation	20%	24%	23%
Field work: Spraying	4%	4%	4%
Field work: Fertilizer application	3%	3%	3%
Field work: Harvesting	9%	9%	9%
Crop storage & drying or cooling	5%	5%	6%
Pesticide manufacture	7%	7%	8%
Fertilizer manufacture	52%	46%	48%
Total	100%	100%	100%
All field work as proportion of total	35%	41%	35%
Field work: proportion as diesel	69%	70%	70%
Field work: proportion as machinery manufacture	31%	30%	30%

The proportion of primary energy usage in baseline period and 2020 is strikingly higher than for the model default mainly due to the higher use of ploughing as the primary cultivation method. Ploughing does more work on soil and thus requires more energy than min-till or direct drilling.

Table 5.2.4.6: Crop outputs of Spring Wheat

Crop outputs (dry matter)	Model default	Average for 2007-2009	Year 2020
DM yield primary crop (grain) t/ha	6.0	5.6	5.8
DM yield secondary crop (straw) t/ha	0.8	2.3	2.3
DM total t/ha	6.8	7.9	8.2
DM for entire crop area (2060 ha)	14,008 t.	16,274 t.	16,892 t.
Output standardised at 14% moisture	15969 t.	18552 t.	19257 t.

Table 5.2.4.7: LCA results aggregated for Spring Wheat

Impact Category	Average values for 2007-2009	Year 2020 values (FH 2020)	Change
Primary energy	44469 GJ.	44888 GJ.	+419 GJ.
GWP (100 yrs)	7977 t. CO_2-e	8164 t. CO_2-e	+1187 t. CO_2-e
Eutrophic Pot.	43 t. PO_4-e	42 t. PO_4-e	-1 t. PO_4-e
Acidification Pot.	41 t. SO_2-e	42 t. SO_2-e	+1 t. SO_2-e
Pesticide Use	14842 dose-ha	15406 dose-ha	+564 dose-ha
Abiotic Resource Use	26 t. Sb-e	27 t. Sb-e	+1 t. Sb-e
Land Use	2876 ha.	2831 ha.	-45 ha.

5.2.5 Spring Oats

Oats is an important crop for the equine industry. It is also used for human consumption in the form of oatmeal (porridge). It has weaker straw than either wheat or barley and it is prone to lodging especially in exposed areas. This has important implications for the input of fertilizer Nitrogen.

Table 5.2.5.1: Input Values for modelling Spring Oats

Input Values	Default values	Average for 2007-2009	Values for 2020
Cultivation Methods	%age by area	%age by area	%age by area
Plough based	57%	95%	95%
Reduced tillage	41%	3%	3%
Direct drilling	2%	2%	2%
Varietal changes and soil			
Increased yield from technology	0%	0%	3%
Proportion clay soil used	9%	15%	15%
Fertilization			
Nitrogen (kg-N/ha)	110	80	80
Proportion of N as urea (%)	8%	0%	0%
Straw Incorporation			
Proportion of straw incorporated	0%	0%	0%

Straw incorporation is set a 0% as oaten straw is a valuable cash crop. However, poor weather in the days after harvesting would render it impossible to bale the straw.

Table 5.2.5.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	Default values	Average for 2007-2009	2020 values
Primary energy used MJ t^{-1}	2,281	2,187	2,158
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	375	330	329
Eutrophic Pot. [kg PO_4 equiv] t^{-1}	2.6	2.0	2.0
Acidification Pot. [kg SO_2 equiv] t^{-1}	1.4	1.0	1.0
Pesticides dose-ha t^{-1}	0.3	0.3	0.3
Abiotic resource use [kg Sb] t^{-1}	1.4	1.3	1.3
*Land use grade 3a ha t^{-1} **	0.182	0.194	0.188
Nitrogen losses			
NO_3-N kg t^{-1} to water	3.6	2.4	2.5
N_2O-N kg t^{-1} to air	0.5	0.4	0.4
NH_3-N kg t^{-1} to air	0.5	0.3	0.3
N_2-N kg t^{-1} to air	3.9	3.7	3.6
Other Emissions			
CO_2 (total) to air kg t^{-1}	141.0	136.6	134.6
CH_4 to air kg t^{-1}	0.2	0.1	0.1
PO_4-P to water kg t^{-1}	0.3	0.3	0.3
K to water kg t^{-1}	0.3	0.4	0.4

Table 5.2.5.3: Relative Proportions of GHG burdens from Spring Oats for baseline period

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.4	296	118.4	46%
CH_4	0.1	25	2.5	1%
CO_2	136.6	1	136.6	53%
Total			257.5	100%

Table 5.2.5.4: Relative Proportions of GHG burdens from Spring Oats for year 2020

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.4	296	118.4	46%

CH_4	0.1	25	2.5	1%
CO_2	134.6	1	134.6	53%
Total			255.5	100%

The proportion of GHG as N_2O is lower for Oats than for either Wheat or Barley, a reflection of the lower level of Nitrogen fertilizer associated with the crop.

Table 5.2.5.5: Primary energy usage proportions associated with Spring Oats crop

Proportion	Default	Average for 2007-2009	Year 2020
Field work: Cultivation	29%	33%	33%
Field work: Spraying	3%	3%	3%
Field work: Fertilizer application	4%	4%	4%
Field work: Harvesting	12%	13%	13%
Crop storage & drying or cooling	6%	7%	7%
Pesticide manufacture	4%	4%	4%
Fertilizer manufacture	43%	37%	37%
Total	100%	100%	100%
All field work as proportion of total	47%	53%	52%
Field work: proportion as diesel	70%	70%	70%
Field work: proportion as machinery manufacture	30%	30%	30%

Table 5.2.5.6: Crop outputs (yields) of Spring Oats

Crop outputs (dry matter)	Model default	Average for 2007-2009	Year 2020
DM yield primary crop (grain) t/ha	4.7	4.4	4.6
DM yield secondary crop (straw) t/ha	2.4	2.4	2.4
DM total t/ha	7.1	6.8	6.9
DM Spring oats entire crop area (834 ha)	5921.4 t.	5671.2 t.	5754.6 t.
Output standardised to 14% moisture	6750 t.	6465 t.	6560 t.

Table 5.2.5.7: LCA results aggregated for Spring Oats

Impact Category	Average values for 2007-2009	Year 2020 values (FH 2020)	Change
Primary energy	14139 GJ.	14156 GJ.	+17 GJ.
GWP (100 yrs)	2133 t. CO_2-e	2158 t. CO_2-e	+25 t. CO_2-e
Eutrophic Pot.	12.9 t. PO_4-e	13.1 t. PO_4-e	+ 0.2 t. PO_4-e
Acidification Pot.	6.5 t. SO_2-e	6.6 t. SO_2-e	+0.1 t. SO_2-e
Pesticide Use	1940 dose-ha	1968 dose-ha	+28 dose-ha
Abiotic Resource Use	8.4 t. Sb-e	8.5 t. Sb-e	+0.5 t. Sb-e
Land Use	1254 ha.	1233 ha.	-21 ha.

5.2.6 Winter Oats

Table 5.2.6.1: Input Values for modelling Winter Oats

Input Values	Default values	Average for 2007-2009	Values for 2020
Cultivation Methods	%age by area	%age by area	%age by area
Plough based	57%	95%	85%
Reduced tillage	41%	3%	13%
Direct drilling	2%	2%	2%
Varietal changes and soil			
Increased yield from technology	0%	0%	5%
Proportion clay soil used	21.7%	18%	22%
Fertilization			
Nitrogen (kg-N/ha)	150	133	130
Proportion of N as urea (%)	18%	0%	0%
Straw Incorporation			
Proportion of straw incorporated	0%	0%	0%

Table 5.2.6.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	Default values	Average for 2007-209	2020 values
Primary energy used MJ t^{-1}	2,437	2,331	2,279
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	415	392	383

Eutrophic Pot. [kg PO_4 equiv] t^{-1}	2.5	2.2	2.0
Acidification Pot. [kg SO_2 equiv] t^{-1}	2.1	1.1	1.1
Pesticides dose-ha t^{-1}	0.8	0.7	0.7
Abiotic resource use [kg Sb] t^{-1}	1.4	1.4	1.4
*Land use grade 3a ha t^{-1} **	0.160	0.166	0.156
Nitrogen losses			
NO_3-N kg t^{-1} to water	3.2	2.9	2.7
N_2O-N kg t^{-1} to air	0.5	0.5	0.5
NH_3-N kg t^{-1} to air	0.8	0.3	0.3
N_2-N kg t^{-1} to air	6.5	5.8	5.5
Other Emissions			
CO_2 (total) to air kg t^{-1}	149.6	143.7	140.6
CH_4 to air kg t^{-1}	0.2	0.2	0.2
PO_4-P to water kg t^{-1}	0.2	0.2	0.2
K to water kg t^{-1}	0.3	0.3	0.3

Table 5.2.6.3: Relative Proportions of GHG burdens from Winter Oats for baseline period

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.5	296	148	50%
CH_4	0.2	25	5.0	1.5%
CO_2	143.7	1	143.7	48.5%
Total			296.7	100

Table 5.2.6.4: Relative Proportions of GHG burdens from Winter Oats for year 2020

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.5	296	148	50.5%
CH_4	0.2	25	5.0	1.5%
CO_2	140.6	1	140.6	48%
Total			293.6	100

Table 5.2.6.5: Primary energy usage proportions associated with Winter Oats crop

Proportion	Default	Average for 2007-2009	Year 2020

Field work: Cultivation	24%	25%	25%
Field work: Spraying	3%	3%	3%
Field work: Fertilizer application	3%	3%	3%
Field work: Harvesting	10%	11%	10%
Crop storage & drying or cooling	6%	6%	6%
Pesticide manufacture	7%	7%	7%
Fertilizer manufacture	47%	45%	45%
Total	100%	100%	100%
All field work as proportion of total	40%	42%	42%
Field work: proportion as diesel	70%	69%	70%
Field work: proportion as machinery manufacture	30%	31%	30%

Table 5.2.6.6: Crop outputs (Yields)of Winter Oats

Crop outputs (dry matter)	Default	Average for 2007-2009	Year 2020 (FH2020)
DM yield primary crop (grain) t/ha	5.4	5.2	5.5
DM yield secondary crop (straw) t/ha	2.0	2.4	2.4
DM total t/ha	7.4	7.6	7.9
DM yield Winter Oats in catchment (1050 ha)*	7,770 t.	7,980 t.	4,148 t.
Output standardised at 14% moisture	8858 t.	9097 t.	4729 t.

Change in output of Winter Oats from baseline to 2020 = -3832 t. DM. The Winter Oats has yielded disappointing results raising questions about its suitability as a crop for the Boyne Catcment. An assumption, therefore, that the area under Winter Oats will be reduced by 50% in 2020. This scenario releases land for maize or field beans production.

Table 5.2.6.7: LCA results aggregated for Winter Oats

Impact Category	Average values for 2007-2009	Year 2020 values (FH 2020)	Change
Primary energy	21205 t. GJ.	10777 t. GJ.	-1042 GJ.
GWP (100 yrs)	3566 t. CO_2-e	1811t. CO_2-e	- 1755 t. CO_2-e
Eutrophic Pot.	20 t. PO_4-e	9 t. PO_4-e	-11 t. PO_4-e
Acidification Pot.	10 t. SO_2-e	5.2 t. SO_2-e	-4.8 t. SO_2-e

Pesticide Use	6368 dose-ha	3310 dose-ha	-3058 dose-ha
Abiotic Resource Use	12.7 t. Sb-e	6.6 t. Sb-e	6.1 t. Sb-e
Land Use	1510 ha.	738 ha.	772 ha.

5.2.7 Main Crop Potatoes

The Boyne Catchment is one of the main potato growing areas. In the baseline period the average area used for potatoes was 1840 ha. Acid Brown Earths and the lighter textured Grey Brown Podzolics are particularly suitable.

Table 5.2.7.1: Input Values for modelling Main Crop Potatoes

Input Values	Default values	Average for 2007-2009	Values for 2020
Varietal changes and soil			
Increased yield from technology	0%	0%	10%
Proportion actually irrigated	56%	25%	40%
Proportion clay soil used	6.9%	5%	5%
Fertilization			
Nitrogen (kg-N/ha)	170	155	160
Proportion of N as urea (%)	0%	0%	0%

If climate predictions of drier, warmer summers (Sweeney *et al.*, 2008) are borne out, it is assumed that the proportion of the potato crop requiring irrigation will increase.

Table 5.2.7.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	Default values	Average for 2007-2009	2020 values
Primary energy used MJ t^{-1}	1,473	1,459	1,449
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	136	136	136
Eutrophic Pot. [kg PO_4 equiv] t^{-1}	0.4	0.4	0.4
Acidification Pot. [kg SO_2 equiv] t^{-1}	0.5	0.4	0.4
Pesticides dose-ha t^{-1}	0.4	0.4	0.4
Abiotic resource use [kg Sb] t^{-1}	0.9	0.9	0.9
*Land use grade 3a ha t^{-1} **	0.021	0.022	0.022

Nitrogen losses			
NO_3-N kg t^{-1} to water	0.6	0.6	0.6
N_2O-N kg t^{-1} to air	0.1	0.1	0.1
NH_3-N kg t^{-1} to air	0.1	0.1	0.1
N_2-N kg t^{-1} to air	0.6	0.6	0.6
Other Emissions			
CO_2 (total) to air kg t^{-1}	87.0	85.8	86.3
CH_4 to air kg t^{-1}	0.1	0.1	0.1
PO_4-P to water kg t^{-1}	0.0	0.0	0.0
K to water kg t^{-1}	0.0	0.1	0.1

Phosphate (PO_4-P) loss to water associated with growing the potato crop was zero in each of the scenarios. This may be a reflection of high infiltration rate in the soil used. Also it may reflect the high water requirement of the crop, where in many cases irrigation is required during the growing season. NO_3-N losses to water are in line with quoted figures in the literature for nitrate losses (Ryan et al., n.d). This may be unavoidable given the highly mobile nature of nitrate in soils.

Table 5.2.7.3: Relative Proportions of GHG burdens from main crop potatoes for baseline period

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.1	296	29.6	25%
CH_4	0.1	25	2.5	2%
CO_2	85.8	1	85.8	73%
Total			117.9	100%

Table 5.2.7.4: Relative Proportions of GHG burdens from main crop potatoes for year 2020

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.1	296	29.6	25%
CH_4	0.1	25	2.5	2%
CO_2	86.3	1	86.3	73%
Total			118.4	100%

The pattern of greenhouse gas emissions associated with main crop potato production is substantially different from that of cereal production. On a per tonne fresh weight basis, CO_2 emissions are dominant, providing almost three-quarters of the GHG burden. Nitrous

Oxide (N_2O) accounts for about one-quarter of the GHG total as opposed to approximately 50% in the case of cereal crops. Whilst the model dictates that emissions are accounted for on per tonne fresh weight basis, it has to be borne in mind, however, that potatoes are a high yield, low dry-matter crop.

Table 5.2.7.5: Primary energy usage proportions associated with main crop potato production

Proportion	Default	Average for 2007-2009	Year 2020
Field work: Cultivation	11%	12%	12%
Field work: Spraying	3%	3%	3%
Field work: Fertilizer application	8%	4%	4%
Field work: Harvesting	9%	9%	9%
Crop storage & drying or cooling	47%	48%	49%
Pesticide manufacture	5%	6%	6%
Fertilizer manufacture	18%	18%	18%
Total	100%	100%	100%
All field work as proportion of total	30%	28%	27%
Field work: proportion as diesel	76%	74%	74%
Field work: proportion as machinery manufacture	24%	26%	26%

The largest energy use component is crop storage & drying or cooling. Almost half of the energy expended is in the storage related category. Main crop potato storage is a specialised energy-intensive process. Main crop potatoes may require storage for several months depending on market conditions.

Since potatoes are entirely different to grain crops on a dry matter basis, the yield is not tabulated on a dry-matter basis. Table 5.2.7.6 gives the tonnage (fresh-weight) for the baseline period (average 2007-2009) and for year 2020. Whilst the crop area remains the same an allowance is made for a 10% increase in yield – average going from 33 tons/ha in the baseline period to 36.3 tons/ha in year 2020. The increased yield is due to technical advances (mainly genetic).

Table 5.2.7.6: Yield of Potatoes (fresh-weight)

Year	Area	Yield/hectare	Total Yield
2007-2009 (avg.)	1840	33 t.	60,720 t.

2020	1840	36.3 t.	66,792 t.

Table 5.2.7.7: LCA results tabulated Main Crop Potatoes

Impact Category	Average values for 2007-2009	Year 2020 values (FH 2020)	Change
Primary energy	88590 GJ.	96782 GJ.	+8192 GJ.
GWP (100 yrs)	8258 t. CO_2-e	9084 t. CO_2-e	+826 t. CO_2-e
Eutrophic Pot.	24.3 t. PO_4-e	26.7 t. PO_4-e	+2.4 t. PO_4-e
Acidification Pot.	24.3t. SO_2-e	26.7 t. SO_2-e	+2.4 t. SO_2-e
Pesticide Use	24.3 dose-ha	26.7 dose-ha	+2.4 dose-ha
Abiotic Resource Use	54.7 t. Sb-e	60.1 t. Sb-e	+5.4 t. Sb-e
Land Use (entire crop)	1840 ha.	1840 ha.	0 ha.

There are increases in Primary Energy Use, GWP and Eutrophication associated with FH2020 scenario

5.2.8 Field Beans

In establishment of the crop, seeds are generally broadcast followed by ploughing to set seeds deeper than they would be set for cereals. An alternative to this method would be strip tillage, also known as minimum inversion. It is a process in which only the narrow strip of land needed for the crop row is tilled.

This crop differs from the other main crops grown in the catchment in that it is Nitrogen fixing and requires no fertilizer N. It is, therefore, important to closely examine the assessment and compare the environmental burdens and resource use of this crop relative to other crops, especially cereals.

As described in Chapter 3, most of the protein component of animal feed has to be imported. This is particularly so in the case of pig production, where high quality soya bean meal has to be imported from South America. The targets of Food Harvest 2020 for dairy, beef and pig meat will result in an enormous increase in the requirement for protein feed. Field Beans grown in the catchment have the potential for a level of import substitution. The area of Field Beans grown in the catchment averaged 190 ha during the baseline period. A doubling of that area could be achieved by 2020 if some of the area devoted to Winter Oats could be turned over to growing Beans. Fortunately, this crop could be grown on some of the heavier soils (Gleys) of the catchment that are marginal for other crops.

Table 5.2.8.1: Input Values for modelling Field Beans

Input Values	Default values	Average for 2007-2009	Values for 2020
Cultivation Methods	%age by area	%age by area	%age by area
Plough based	57%	95%	85%
Reduced tillage	43%	5%	15%
Direct drilling	0%	0%	0%
Varietal changes and soil			
Increased yield from technology	0%	0%	5%
Proportion clay soil used	38.9%	20%	20%
Fertilization			
Nitrogen (kg-N/ha)	0	0	0
Proportion of N as urea (%)	0	0	0
Straw Incorporation			
Proportion of straw incorporated	100%	100%	100%

Table 5.2.8.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	Default values	Average for 2007-2009	2020 values
Primary energy used MJ t^{-1}	2,514	2,544	2,431
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	508	514	501
Eutrophic Pot. [kg PO_4 equiv] t^{-1}	5.9	6.1	5.8
Acidification Pot. [kg SO_2 equiv] t^{-1}	2.1	2.2	2.1
Pesticides dose-ha t^{-1}	1.1	1.1	1.1
Abiotic resource use [kg Sb] t^{-1}	1.3	1.4	1.3
*Land use grade 3a ha t^{-1} **	0.312	0.320	0.304
Nitrogen losses			
NO_3-N kg t^{-1} to water	9.4	9.9	9.4
N_2O-N kg t^{-1} to air	0.6	0.6	0.6
NH_3-N kg t^{-1} to air	0.7	0.7	0.7
N_2-N kg t^{-1} to air	3.1	3.2	3.0

Other Emissions			
CO_2 (total) to air kg t^{-1}	181.4	183.4	175.4
CH_4 to air kg t^{-1}	0.0	0.0	0.0
PO_4-P to water kg t^{-1}	0.5	0.5	0.5
K to water kg t^{-1}	0.6	0.6	0.6

Nitrate loss to water is sometimes more appropriately viewed using area based indicators rather than product based indicators. Loss of NO_3 per hectare is more meaningful and comprehensible than loss of NO_3 per tonne of product. In any case, emission of nitrate to water is in line with expectation (approximately 30 kg ha^{-1})

Table 5.2.8.3: Relative Proportions of GHG burdens from field beans for baseline period

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.6	296	177.6	49%
CH_4	0.0	25	0.0	0%
CO_2	183.7	1	183.7	51%
Total			361.3	100%

The emissions profile is characterised by zero emissions for CH_4 and almost equal GHG burden from CO_2 and N_2O.

Table 5.2.8.4: Relative Proportions of GHG burdens from field beans for year 2020

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.6	296	177.6	50%
CH_4	0.0	25	0.0	0%
CO_2	175.4	1	175.4	50%
Total			353.0	100%

In the 2020 scenario, GHG emissions burdens are equally divided between CO_2 and N_2O. Emissions of CH_4 remain zero.

Table 5.2.8.5: Primary energy usage proportions associated with Field Beans crop

Proportion	Default	Average for 2007-2009	Year 2020
Field work: Cultivation	46%	47%	46%
Field work: Spraying	6%	5%	5%
Field work: Fertilizer application	6%	6%	6%

Field work: Harvesting	19%	19%	19%
Crop storage & drying or cooling	6%	6%	7%
Pesticide manufacture	7%	7%	7%
Fertilizer manufacture*	7%	7%	7%
Total	100%	100%	100%
All field work as proportion of total	77%	77%	77%
Field work: proportion as diesel	70%	70%	70%
Field work: proportion as machinery manufacture	30%	30%	30%

Fertilizer manufacture in this case means extraction and processing of phosphate and potash. These are required inputs to grow the crop. The energy burden is, however, quite low compared with the manufacture of Nitrogenous fertilizer. However, it must be borne in mind that phosphate and potash are non-renewable resources and prudent recycling is required for long term sustainability.

Table 5.8.2.6: Crop outputs (Yields) of Field Beans

Crop outputs (dry matter)	Default	Average for 2007-2009	Year 2020
DM yield primary crop (beans) t/ha	2.8	2.7	2.8
DM yield secondary crop (straw) t/ha	0.0	0.0	0.0
DM total t/ha	2.8	2.8	2.8
DM yield Field Beans in catchment (190 ha)*		532	2,002
Output standardised to 8% moisture		575	2162

*The assumption is that an extra 525 ha will be turned over from Winter Oats to grow beans on a total of 715 ha by 2020. The assumption is that straw will be incorporated to build fertility in the crop rotation.

Table 5.2.8.7: LCA results aggregated for Field Beans

Impact Category	Average values for 2007-2009	Year 2020 values (FH 2020)	Change
Primary energy	1463 GJ.	5256 GJ.	+3793 GJ.
GWP (100 yrs)	296 t. CO_2-e	1083 t. CO_2-e	+787 t. CO_2-e
Eutrophic Pot.	3.50 t. PO_4-e	12.50 t. PO_4-e	+9 t. PO_4-e
Acidification Pot.	1.3 t. SO_2-e	4.5 t. SO_2-e	+3.5 t. SO_2-e
Pesticide Use	632 dose-ha	2378 dose-ha	+746 dose-ha

Abiotic Resource Use	0.8 t. Sb-e	2.8 t. Sb-e	+2 t. Sb-e
Land Use	190 ha.	715 ha.	+525 ha.

5.2.9 Forage Maize

In the baseline period, Maize was grown for silage on an average of 11,600 hectares in the catchment. The Food Harvest 2020 target for dairying (50% increased output) will require a significant increase in the area of Maize to supply winter feed for the extra cows. For the purpose of this study it is assumed that an extra 3,000 hectares will be transferred from low profitability suckler beef and sheep systems. Many of the dairy farmers wishing to increase cow numbers will be constrained by the size of the grazing platform. Areas of the farm currently used to produce grass silage will have to be given over to grazing. On many farms, this will require the importation of a substantial quantity of Maize silage. The projected climate change for the area would suggest a trend towards warmer, drier summers (Murphy and Charlton, 2006; Sweeney *et al.*, 2008). This change would be highly favourable for Maize growing.

Table 5.2.9.1: Input Values for modelling Forage Maize

Input Values	Default values	Average for 2007-2009	Values for 2020
Cultivation Methods	% by area	% by area	% by area
Plough based	57%	95%	90
Reduced tillage	41%	3%	8%
Direct drilling	2%	2%	2%
Varietal changes and soil			
Increased yield from technology	0%	0%	5%
Proportion clay soil used	54.8%	10%	20%
Fertilization			
Nitrogen (kg-N/ha)*	100*	120*	100*
Proportion of N as urea (%)	10%	0%	0%

It is important to implement a proper nutrient management plan whereby the appropriate amount of slurry is recycled back to the land on which the Maize was grown. In the figures above for fertilizer nitrogen usage, there is an assumption that 33m^3/ha of cattle slurry is recycled on to the ground where the Maize is grown. This is ploughed in soon after spreading to avoid ammonia volatilisation. Alternatively, where pig slurry is to be used for growing Maize, it is important that there is strict compliance with IPC licencing conditions governing the operation of the pig unit. Use of Urea as a source of nitrogen would not feature for maize growing in the Boyne Catchment. Accordingly, the input value for Urea was adjusted to zero. The default soil type associated with maize growing in England and Wales is clay dominated. Clay soil would not be regarded as optimal for growing maize in the catchment area. The model default was therefore adjusted appropriately. Table 5.2.9.2 presents the environmental burdens and impacts associated with Maize growing under the prevailing conditions in the catchment.

Table 5.2.9.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	Default values	Average for 2007-2009	2020 values
Primary energy used MJ t^{-1}	1,706	1,737	1,654
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	303	332	306
Eutrophic Pot. [kg PO_4 equiv] t^{-1}	1.8	2.5	1.9
Acidification Pot. [kg SO_2 equiv] t^{-1}	1.2	0.8	0.7
Pesticides dose-ha t^{-1}	0.3	0.3	0.2
Abiotic resource use [kg Sb] t^{-1}	1.8	1.8	1.8
*Land use grade 3a ha t^{-1} **	0.091	0.094	0.088
Nitrogen losses			
NO_3-N kg t^{-1} to water	2.8	4.3	3.1
N_2O-N kg t^{-1} to air	0.4	0.4	0.4
NH_3-N kg t^{-1} to air	0.4	0.2	0.2
N_2-N kg t^{-1} to air	2.8	3.3	2.6
Other Emissions			
CO_2 (total) to air kg t^{-1}	108.5	109.8	104.7
CH_4 to air kg t^{-1}	0.2	0.2	0.1
PO_4-P to water kg t^{-1}	0.1	0.1	0.1
K to water kg t^{-1}	0.2	0.2	0.2

*Land Use: The values in the table would indicate rather low yields of forage Maize and are not representative of the yields of fresh material obtainable in the Boyne Catchment. Typically yields in the target area would be 30-50 tonnes of fresh-weight per hectare.

Table 5.2.9.3: Relative Proportions of GHG burdens from forage maize for baseline period

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.4	296	118.4	51%
CH_4	0.2	25	5.0	2%
CO_2	109.8	1	109.8	47%
Total			233.2	100%

Table 5.2.9.4: Relative Proportions of GHG burdens from forage maize [year 2020]

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	0.4	296	118.4	52%
CH_4	0.1	25	5.0	2%
CO_2	104.7	1	104.7	46%
Total			228.1	100%

CO_2 and N_2O are the dominant greenhouse gases. Emission of methane is insignificant. When the Maize silage crop is examined from a dry matter perspective, there are greater emissions of CO_2 and N_2O than for cereal crops. Maize silage is approximately 30% dry matter at harvesting whereas cereal grains are harvested at about 80% dry matter.

Table 5.2.9.5: Primary energy usage proportions associated with forage maize crop

Proportion	Default	Year 2010	Year 2020
Field work: Cultivation	20%	18%	19%
Field work: Spraying	5%	5%	5%
Field work: Fertilizer application	3%	3%	3%
Field work: Harvesting	11%	11%	11%
Crop storage & drying or cooling	4%	4%	5%
Pesticide manufacture	2%	2%	2%
Fertilizer manufacture	55%	58%	56%
Total	100%	100%	100%
All field work as proportion of total	38%	36%	37%
Field work: proportion as diesel	74%	73%	74%
Field work: proportion as machinery manufacture	26%	27%	26%

Despite the fact that slurry substitutes for a portion of the fertilizer requirement, there is still a substantial energy requirement for fertilizer manufacture.

Table 5.2.9.6: Crop Output (Yields) of Forage Maize

Year	Area	Tonnes/ha.	Total yields
2007-2009 (avg.)	11,600 ha.	50	580,000 tonnes
2020	14,600 ha	55	803,000 tonnes

Table 5.2.9.7: LCA Results aggregated for Forage Maize

Impact Category	Average values for 2007-2009	Year 2020 values (FH 2020)	Change
Primary energy	1,007,460 GJ.	1,328,162 GJ.	+320,702 GJ.
GWP (100 yrs)	192,560 t. CO_2-e	245,718 t. CO_2-e	+53,158 t. CO_2-e
Eutrophic Pot.	1450 t. PO_4-e	1526 t. PO_4-e	+ t. PO_4-e
Acidification Pot.	1450 t. SO_2-e	1526 t. SO_2-e	+76 t. SO_2-e
Pesticide Use	174,000 dose-ha	166,000 dose-ha	-8000 dose-ha
Abiotic Resource Use	1044 t. Sb-e	1446 t. Sb-e	+402 t. Sb-e
Land Use*	11,600 ha.	14,600 ha.	+3000 ha.

*Values for Land Use as an impact category in the Cranfield Model are substantially at variance with the reality in the target area (i.e. Boyne Catchment). The difference is too great be accounted for by difference in yields between different regions. It is assumed that the dry matter yield was inadvertently used instead of the fresh weight yield. The average value for land use was used in this study.

5.2.10 Oilseed Rape

The average area of oilseed rape grown in in the catchment during the baseline period was 1192 ha. The main varieties grown in the catchment are dual-purpose, providing a bio-fuel as a diesel substitute and a residual protein meal suitable for all types of livestock. The latter is a valuable co-product and can be used as a justification in the debate concerning land use for food versus fuel.

Table 5.2.10.1: Input Values for modelling Oilseed Rape

Input Values	Default values	Average for 2007-2009	Values for 2020
Cultivation Methods	%age by area	%age by area	%age by area
Plough based	50%	85%	80%
Reduced tillage	45%	10%	15%
Direct drilling	5%	5%	5%
Varietal changes and soil			
Increased yield from technology	0%	0%	5%
Proportion clay soil used	42.8%	20%	20%
Fertilization			
Nitrogen (kg-N/ha)	195	220	200
Proportion of N as urea (%)	31%	20%	30%
Straw Incorporation			
Proportion of straw incorporated	100%	100%	100%

Although the straw of OSR can be baled and used for firing boilers, it is currently more usual for the straw to be ploughed in (incorporated). Cultivation for OSR in the catchment is mostly plough-based at this point in time, although OSR can be satisfactorily established using reduced cultivation or direct drilling. OSR is highly demanding on fertilizer nitrogen.

Table 5.2.10.2: Output values: Average Environmental Burdens and Impacts, t^{-1} (fresh weight)

Impacts & resources used	Default values	Average for 2007-2009	2020 values
Primary energy used MJ t^{-1}	5,279	5,541	5,288
GWP (100 yrs)[kg CO_2 equiv] t^{-1}	1,048	1,154	1,059
Eutrophic Pot. [kg PO_4 equiv] t^{-1}	8.6	10.1	8.9
Acidification Pot. [kg SO_2 equiv] t^{-1}	7.3	6.3	7.3
Pesticides dose-ha t^{-1}	1.0	0.9	0.9
Abiotic resource use [kg Sb] t^{-1}	2.9	3.1	2.9
*Land use grade 3a ha t^{-1} **	0.319	0.317	0.312
Nitrogen losses			
NO_3-N kg t^{-1} to water	13.2	17.1	14.2
N_2O-N kg t^{-1} to air	1.4	1.6	1.4

NH_3-N kg t^{-1} to air	2.9	2.5	2.9
N_2-N kg t^{-1} to air	27.6	31.3	26.4
Other Emissions			
CO_2 (total) to air kg t^{-1}	316.3	330.1	316.1
CH_4 to air kg t^{-1}	0.5	0.5	0.5
PO_4-P to water kg t^{-1}	0.5	0.5	0.5
K to water kg t^{-1}	0.6	0.6	0.6

Although OSR provides a bio-fuel, as the figures above show, its balance sheet is not carbon neutral and there are substantial other environmental (non-carbon) footprints as well. GWP is substantially larger than the values for cereal crops, approximately double that of Winter Wheat, for example. Primary energy used to grow the crop is more than double the average used for growing cereal crops. Eutrophication and Acidification Potentials for OSR are substantially higher than the figures for cereal growing.

Some positive aspects to OSR are its role in import substitutions. It replaces some imported fossil fuel and its residue of protein meal can displace some of the 600,000 tons of imported Soya products from South America, some of which is grown on recently deforested land in the Amazon basin.

Table 5.2.10.3: Relative Proportions of GHG burdens from Oilseed Rape for baseline period

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	1.6	296	473.6	58%
CH_4	0.5	25	12.5	1.5%
CO_2	330.1	1	330.1	40.5%
Total			816.2	100%

Table 5.2.10.4: Relative Proportions of GHG burdens for Oilseed Rape [year 2020]

GHG	Emission level (kg t^{-1} fresh weight)	GWP	Total burden Kg CO_2-equiv.	Total burden %
N_2O	1.4	296	414.4	56%

CH_4	0.5	25	12.5	2%
CO_2	316.1	1	316.1	42%
Total			743.0	100%

In the baseline period and 2020 emissions of the greenhouse gases N_2O and CO_2 were substantial compared to the other crops that have been modelled.

Table 5.2.10.5: Primary energy usage proportions associated with oilseed rape crop

Proportion	Default	Average for 2007-2009	Year 2020
Field work: Cultivation	21%	20%	21%
Field work: Spraying	4%	3%	4%
Field work: Fertilizer application	3%	3%	3%
Field work: Harvesting	8%	8%	8%
Crop storage & drying or cooling	3%	3%	3%
Pesticide manufacture	$%	4%	4%
Fertilizer manufacture	57%	59%	57%
Total	100%	100%	100%
All field work as proportion of total	36%	34%	35%
Field work: proportion as diesel	71%	71%	71%
Field work: proportion as machinery manufacture	29%	29%	29%

Table 5.2.10.6: Crop outputs (Yields) of Oilseed Rape

Crop outputs (dry matter)	Default	Average for 2007-2009	Year 2020
DM yield primary crop (beans) t/ha	2.9	2.9	3.0
DM yield secondary crop (straw) t/ha	0.0	0.0	0.0
DM total t/ha	2.9	2.9	3.0
DM yield Oilseed Rape in catchment (1192 ha)*	3456.8	3456.8 t.	3576.0 t.
Output at 8% moisture content		3733 t.	3858 t.

It is assumed that there is no increase in area of OSR associated with FH2020

Table 5.2.10.7: Aggregation of LCA results for Oilseed Rape

Impact Category	Average values for 2007-2009	Year 2020 values (FH 2020)	Change
Primary energy	20685 GJ.	20401 GJ.	-284 GJ.
GWP (100 yrs)	4308 t. CO_2-e	4086 t. CO_2-e	-222 t. CO_2-e
Eutrophic Pot.	37.7 t. PO_4-e	34.3 t. PO_4-e	-11 t. PO_4-e
Acidification Pot.	23.5 t. SO_2-e	28.1 t. SO_2-e	-4.6 t. SO_2-e
Pesticide Use	3360 dose-ha	3472 dose-ha	+112 dose-ha
Abiotic Resource Use	11.5 t. Sb-e	11.1 t. Sb-e	-0.4 t. Sb-e
Land Use*	1183 ha.	1204ha.	+21 ha.

What are the environmental consequences that flow from crop production changes under the Food Harvest 2020 regime?

The absolute values of change for each environmental impact are set out in 5.2.11.1.

Table 5.2.11.1 Aggregate of environmental impact changes for crop production (absolute values)

Environmental Impact Category	Change resulting from FH2020 (+/-)
Primary Energy	Increase of 325,175 GJ (gigajoules)
Global Warming Potential	Increase of 51,605 tonnes CO_2 equivalent
Eutrophication Potential	Increase of 38.2 tonnes CO_2 equivalent
Acidification Potential	Increase of 70 tonnes SO_2 equivalent
Pesticide Use	Decrease of 7495 dose-hectare
Abiotic Resource Use	Increase of 422 tonnes antimony equivalent
Land Use	Increase of 4748 hectares

The changes arising from implementation of FH2020 (expressed as a percentage) for each environmental impact category are set out in 5.2.11.2

Table 5.2.11.2: Aggregate of environmental consequences for all crops

Environmental Impact Category	Change resulting from FH2020 (+/-)
Primary Energy	Increase of 20%
Global Warming Potential (100 years)	Increase of 17%
Eutrophication Potential	Increase of 22%
Acidification Potential	Increase of 4%
Pesticide Use	Decrease of 1.5%
Abiotic Resource Use	Increase of 29%
Land Use	Increase of 7%

Inference:

There is a substantial increase in primary energy usage associated with the arable component of Food Harvest 2020 mainly attributable to growing an extra 3000 ha of forage maize in 2020 which is a high user of energy. The field operations are energy intensive. It should be borne in mind, however, that maize typically produces two to three times more dry matter per hectare than cereal crops.

In the case of Global Warming Potential, there is an increase in the emission of greenhouse gases. The increase is largely associated with the maize crop, especially the additional area of maize (3000 ha) for 2020.

Eutrophication Potential is increased by 22% (50 tonnes PO_4-equivalent). Although this appears high it is manageable when compared with the livestock enterprises of the catchment.

Acidification Potential is increased by 4% in the arable component of the Food Harvest 2020 scenario. This is in line with expectation.

Pesticide Use remains almost unchanged under crop production in the Food Harvest 2020 scenario. This is in line with expectation.

Abiotic Resource Use is increased substantially under the crop production component of Food Harvest 2020. It is not an immediate concern for the catchment as it is more a global issue of non-renewable resource depletion.

Land Use is reasonably well balanced for crop production and poses no significant issue in relation to Food Harvest 2020.

Chapter 6

Environmental Burdens of animal production in Boyne Catchment

This chapter examines the environmental impacts of the main livestock enterprises in the Boyne Catchment (Dairy, Beef, Sheep and Pigs) in the light of the targets set out for Food Harvest 2020.

6.1 Environmental Impact of Milk Production in the Boyne Catchment

The average number of dairy cows in the catchment for the baseline period was 52,228. An estimate of the calving pattern was 20% autumn calving and 80% spring calving. There is a market requirement for milk produced across the winter for the liquid trade as well as manufacturing milk for high value branded speciality products like cream liquors. The majority of milk producers, however, have a preference for the spring calving pattern rather than the more onerous autumn calving pattern.

The Food Harvest 2020 plan envisages a 50% increase in milk production. The delivery of that target requires the following drivers:

a. Increased number of cows
b. Higher milk yields per cow per year

In this study an assumption is made that by the year 2020 there will be an increase in cow numbers of 25% and an increase in milk yields per cow of 20%. This combination provides the basis for delivery of a 50% increase in milk production as specified in Food Harvest 2020.

CSO estimates of average milk yield per cow are based on total milk supplied to creameries and processors per registered live dairy cow. The actual average per cow yield is likely to be higher than the CSO estimate because of milk fed to calves and the presence in the herd of non-productive cows. Average milk yield per cow from Irish Cattle Breeding Federation (ICBF) officially recorded herds (approximately one third of the dairy farms) are higher than the CSO figure (for the reasons stated above). The national average milk yield per cow for the baseline period was 6723 litres (ICBF website, 2012). It is plausible to assume that the farmers in milk recording schemes are the more efficient and progressive ones. This is likely to impart an upward bias in the calculation of average milk yield. On the other hand, there is a higher than average proportion of winter milk production in the Boyne catchment – a system usually associated with higher milk yields. Accordingly, on the basis of available data and expert opinion from extension advisers, average milk yield per cow in the catchment was estimated at 6850 litres.

6.1.1 Modelling Milk Production in the Boyne Catchment

Data used in the assumptions and model inputs are from a diverse range of sources that included CSO, DAFF, ICBF (Irish Cattle Breeding Federation) and Teagasc. The data and parameters used in the study are believed by expert opinion to be representative of dairy farming in the Boyne Catchment.

Assumptions

It is assumed that dairy cows in the catchment are predominantly of the Holstein-Friesian breed. Milk composition is standardised at 4.1% butter fat and 3.3% protein.

Table 6.1.1: Technical Parameters (per cow unit) used in the milk production model

System Calving Pattern	**Autumn Calving**			**Spring Calving**		
Milk Yield Category	Low	Medium	High	Low	Medium	High
Milk, litres per year	5850	6850	7850	5850	6850	7850
Milk, litres per lactation	5946	7225	8603	5946	7225	8603
Calving Index, days	371	385	400	371	385	400
Productive life, lactations	4.5	3.8	3.16	4.5	3.8	3.16
Replacement heifers/lact	0.223	0.263	0.317	0.223	0.263	0.317
Cow weight, kg	598	630	659	598	630	659
Cow mortalities, %	1%	1%	1%	1%	1%	1%
Cow casualties, %	5.98%	6.3%	6.59%	5.98%	6.3%	6.59%
Calf mortalities %	10%	10%	10%	10%	10%	10%
Calf weight, kg	45	45	45	45	45	45
Calf casualties, %	4.5%	4.5%	4.5%	4.5%	4.5%	4.5%
Female dairy calves	0.223	0.263	0.317	0.223	0.263	0.317
Male dairy calves	0.232	0.274	0.330	0.232	0.274	0.330
Female dairy X calves	0.211	0.155	0.086	0.211	0.155	0.086
Male dairy X calves	0.219	0.161	0.089	0.219	0.161	0.089
Volunt. feed intake. Kg DM	6141	6786	7450	6141	6786	7450
Energy needs MJ [ME] / lact.	61807	71662	82162	61807	71662	82162
Maize proportion of silage	0.0	0.2	0.5	0.0	0.2	0.5
Prop. forage as grazed grass	0.4	0.4	0.4	0.6	0.6	0.6
Concentrates, kg DM /lact.	1586	1914	2047	842	1180	1382

Prop. diet concentrates	0.26	0.28	0.27	0.14	0.17	0.19
Grazing, kg DM/lactation	1822	1949	2161	3179	3364	3641
Forage DM need, kg DM/lact	4555	4872	5403	5299	5606	6068
Grass silage, kg DM/lact	2733	2339	1621	2120	1794	1214
Maize silage, kg DM/lact	0	585	1621	0	448	1214

Some key variables were changed from the default values to alternatives that more accurately reflect the pattern of milk production in the Boyne Catchment for the baseline period, i.e. the average of 2007, 2008 and 2009. Some of the variables remained at the default values.

Table 6.1.2: Key Variables for inputs to model for milk production in baseline period

Parameter	Default Value	Alternative Value
Autumn Calving	50%	20%
Spring Calving	50%	80%
Maize silage %	20%	20%
Low yielders	20%	60%
Mid Yielders	55%	30%
High Yielders	25%	10%
*Spread in milk yield distribution of L/M/H (litres/yr)	1000	1000
Calving index, days	385	375
Average number of lactations in herd	3.8	4.5
Voluntary feed intake (vs. standard value)	100%	100%
Change in longevity (days in milk) with increasing yield, days/1000 ltr.	-200	-200
Butterfat concentration, %	4.1%	4.1%
Protein concentration, %	3.3%	3.3%

*Yield categories low, medium and high are separated by increments of 1000 litres

Running the Cranfield LCA model based on the parameters in tables 6.1.1 and 6.1.2 above gave the following outputs for environmental burdens and impacts. The calculated results are based on a functional unit of 10,000 litres of milk with composition of 4.1% butterfat and 3.3% protein

Table 6.1.3: Output Values: Average Environmental Burdens and Impacts/ 10,000 litres for the baseline period

Impacts and resources used	Average Values for 2007-2009
Primary energy used [MJ] 10,000 litres^{-1}	25,967 MJ (26GJ)
GWP(100yrs)[kg CO_2 equiv] 10,000 litres^{-1}	10,647 kg (10.6 tonnes)
Eutrophication Potential [kg PO_4 equiv] 10,000 litres^{-1}	40 kg
Acidification Potential [kg SO_2 equiv] 10,000 litres^{-1}	94 kg
Pesticide Use [dose-ha]10,000 litres^{-1}	1.1 dose

Abiotic Resource Use [kg Sb equiv] 10,000 litres^{-1}	22 kg
Land Use hectares 10,000 litres^{-1}	1.18 ha
Nitrogen Losses[kg 10,000 litres-1]	
NO_3 –N to water [kg 10,000litres^{-1}]	51 kg
N_2O-N to air [kg 10,000 litres^{-1}]	6 kg
NH_3-N to air [kg 10,000 litres^{-1}]	42 kg
Other Emissions	
CO_2 total to air [kg 10,000 litres^{-1}]	1,635 kg
CH_4 to air [kg 10,000 litres^{-1}]	241 kg
PO4-P to water [kg 10,000 litres^{-1}]	0.4 kg

Primary Energy Use

The result for this impact category is in line with expectation. A high dependence on imported fossil fuel would increase the impact relative to other countries with a different fuel mix that includes a larger proportion of renewables.

Global Warming Potential [GWP]

The GWP is low by European standards. This result is in line with expectation and provides further evidence that milk produced under Irish conditions has a low Carbon intensity. As mentioned in Chapter 3, JRC carried out a carbon footprint of milk production across the EU-27. The JRC results put Ireland and Austria jointly at the lowest level on the scale (1 kg CO_2-eq. per kg of milk produced). This is almost identical to the GWP value from the model used in this study (Table 6.1.3). The average footprint for the EU-27 was 1.4 kg CO_2-eq.

Eutrophication Potential

On the basis that production of one functional unit (10,000 litres) takes approximately 1 hectare of land in the catchment area, this result is broadly in line with expectation as loss of both nitrate and phosphate from run-off are drivers for eutrophication of surface water. Although there are several pathways for loss of nitrogen, empirical evidence from other sources (Shortle and Jordan, 2012) would support the result derived from the model. The assumptions used in modelling would ensure that the average milk production farm in the catchment had a stocking density that was compliant with the Nitrates Directive. It was assumed that those milk producers in the catchment that exceeded the directive threshold for organic nitrogen had successfully applied for derogation from the directive that would have allowed them to exceed the threshold for organic nitrogen.

Acidification Potential

This is in line with expectation as there are several agriculture related factors contributing to acidification. There are a number of emissions that contribute, e.g. $NH_{3,}$ $NO_{3,}$ NO_x.

Pesticide Use

The model output for this impact category suggests that pesticide use in Irish dairy farming is low. Grassland farming has a low dependency on pesticides compared with arable cropping systems.

Abiotic Resource Use

This is in line with expectation. Farmers have significant scope for the recycling of materials. Recycling of plastic materials are commonplace. All areas within the catchment have a local service for collection of used silage wrap for recycling. Collection of scrap metals, copper, lead, iron etc., for recycling is readily available.

Land Use

As dairy farms are widely dispersed throughout the catchment and carried out on a wide range of soils, data of soils and land use categories were not available in the spatial detail that would ideally be desirable. Accordingly, the global figure for the catchment of 1.18 hectares per functional unit may be the best that is available and serve the purpose of this study.

Scaling up from functional unit to total milk production in the catchment (baseline period)

The estimated average for total annual milk production in the catchment during the baseline period was 33, 163 X 10^4 litres i.e. 33,163 Functional Units. The outputs from the Cranfield LCA model are scaled up from functional unit (FU)-based values to values based on total milk production in the catchment. These results are presented in Table 6.1.4

Table 6.1.4: Average Environmental burdens of total milk produced in the catchment during baseline period

Environmental Impacts and resources used	**Model output values per functional unit (FU)**	**Total FUs**	**Total impact/ resource use for milk production (catchment)**
Primary energy	26 GJ	33,163	862,238 GJ
GWP	10.647 t. CO_2-e	33,163	353,086 tonnes CO_2-e
Eutrophication potential	40 kg PO_4-e	33,163	1327 tonnes PO_4-e
Acidification potential	94 kg SO_2-e	33,163	3117 tonnes SO_2-e
Pesticide use	1.1 dose-ha	33,163	3,6479 dose-ha
Abiotic Resource use	2.2 kg Sb-e	33,163	72,959 tonnes Sb-e
Land use	1.2 Hectares	33,163	39796 ha
Nitrogen losses			
NO_3-N to water	51 kg	33,163	1691 tonnes NO_3-N
N_2O-N to air	6 kg	33,163	199 tonnes N_2O-N
NH_3-N to air	42 kg	33,163	1,393 tonnes NH_3-N
Other Emissions			
CO_2 (total) to air	1,635 kg	33,163	54,222 tonnes CO_2
CH_4 to air	241 kg	33,163	7992 tonnes CH_4
PO_4-P to water	0.4 kg	33,163	13.3 tonnes

1 gigajoule(GJ) = 1000 megajoule (MJ)

In addition to the seven impact categories, the disaggregated chemical species under 'Nitrogen Losses' and 'Other emissions' (above) highlight the hotspot burdens associated with milk production in the catchment. In the case of the nutrient drivers for eutrophication, there is a large quantitative imbalance between nitrate and phosphate emissions to water. This indicates that phosphate is the limiting nutrient in the growth of algae. Efforts to limit eutrophic conditions should therefore be primarily focused on preventing the ingress of phosphate to surface water. Approximately half of the Nitrogen lost is in the form of nitrate to surface and ground water. Such large losses of nitrate to water points up in a compelling way the need for the EU Nitrates Directive and adherence to the conditions of that directive if water resources are to be protected for the future.

Increasing milk output by 50% for Food Harvest 2020

As previously stated this objective can be achieved by increasing cow numbers by 25% and cow yields by 20%. In this scenario, the number of dairy cows will go from 52228 to 65285 and average milk yield per cow will go from 6350 litres to 7620 litres. Some inputs to the model needed to be changed to accommodate the increased milk yield profile.

For the purpose of this study it is assumed that the increase in dairy cow numbers will be accompanied by a decrease in suckler cow numbers. For the purpose of this study it is assumed that each unit increase in dairy cows will be accompanied by 0.8 unit decrease in suckler cows. Beef production using suckler cows is not financially rewarding without substantial subsidies. The introduction (2005) of decoupling of premiums from levels of production eliminated the incentives for farmers to manage their cattle enterprises so as to maximize direct payment of subsidies. It should be remembered that expansion of the suckler cow herd was largely driven by the Suckler Cow Premium which was introduced in 1981. There followed a rapid escalation of the national suckler cow herd from 410,000 in 1981 to peak at nearly 1,200,000 in 1998. Another factor in this unprecedented expansion was the imposition of milk quotas in 1983 that precluded any further expansion in the dairy sector. A significant decrease in suckler cow numbers over the next few years is a plausible scenario as the system is now at best weakly incentivised. With the abolition of milk quotas in 2015, young farmers with adequate land resources wishing to make a full time career in farming are likely to consider changing over to relatively profitable milk production. Other suckler beef producers may change over to contract rearing of replacement heifers for dairy farmers. Older farmers wishing to exit beef production may lease their land to neighbouring dairy farmers who wish to expand milk production.

Modelling Milk Production for Year 2020

Some changes in model inputs were made, where this was required, to reflect the more intensive production regime in 2020. Some inputs were changed but others remained unchanged. Once again, compliance with the organic nitrogen limits of the Nitrates Directive was retained on the basis that it cannot be assumed that the option of derogation from the Nitrates Directive will be renewed indefinitely.

Table 6.1.5: Key Variables for inputs to model for milk production in 2020

Parameter	Default Value	Alternative Value
Autumn Calving	50%	25%
Spring Calving	50%	75%
Maize silage %	20%	20%
Low yielders	20%	10%
Mid Yielders	55%	20%
High Yielders	25%	70%
*Spread in milk yield distribution of L/M/H (litres/yr)	1000	1000
Calving index, days	385	395
Average number of lactations in herd	3.8	3.8
Voluntary feed intake (vs. standard value)	100%	100%
Change in longevity (days in milk) with increasing yield, days/1000 ltr.	-200	-200
Butterfat concentration, %	4.1%	4.0%
Protein concentration, %	3.3%	3.4%

Running the milk production model for the systems mix and technical parameters that prevailed in the baseline years gave the results presented Table 6.1.6.

Table 6.1.6: Output Values: Average Environmental Burdens and Impacts/ 10,000 litres for year 2020

Impacts and resources used	Average Values for 2007-2009
Primary energy used [MJ] 10,000 litres^{-1}	24, 492 MJ (24.5 GJ)
GWP(100yrs)[kg CO_2 equiv] 10,000 litres^{-1}	10,034 kg (10.0 tonnes)
Eutrophication Potential [kg PO_4 equiv] 10,000 litres^{-1}	38 kg
Acidification Potential [kg SO_2 equiv] 10,000 litres^{-1}	88 kg
Pesticide Use [dose-ha]10,000 litres^{-1}	1.3 kg
Abiotic Resource Use [kg Sb equiv] 10,000 litres^{-1}	21 kg
Land Use [grade 3a hectares] 10,000 litres^{-1}	1.18 ha
Nitrogen Losses[kg 10,000 litres-1]	
NO_3 –N to water [kg 10,000litres^{-1}]	46 kg
N_2O-N to air [kg 10,000 litres^{-1}]	5.6 kg
NH_3-N to air [kg 10,000 litres^{-1}]	39 kg
Other Emissions	
CO_2 total to air [kg 10,000 litres^{-1}]	1,544 kg
CH_4 to air [kg 10,000 litres^{-1}]	228 kg
PO4-P to water [kg 10,000 litres^{-1}]	0.5 kg

Results of modelling milk production for year 2020

There is a slight downward trend across most environmental impact categories and individual chemical emissions when compared with the baseline values. The Global Warming Potential per functional unit is somewhat reduced and is very low by international comparisons. Nitrate emission to water is slightly lower but still remains high and it is difficult to see how derogation from the Nitrates Directive can be considered as being indefinitely sustainable into the future. One of the key issues governing the sustainability of any food production system is the impact it has on local water supplies. Clearly there is no room for complacency.

Scaling up from functional unit to total milk production in catchment (Year 2020)

The expectation (estimate) is that total milk production in the catchment in 2020 will be approximately 48,637 X 10^4 litres i.e. 48,637 functional units. The outputs from the Cranfield LCA model were again scaled up from functional unit (FU) to totality of environmental burdens and resource use associated with milk production in the catchment in year 2020.

Table 6.1.7: Average Environmental burdens of total milk produced in the catchment for 2020

Environmental Impacts and resources used	Model output values per functional unit (FU)	Total FUs	Total impact/ resource use for milk production (catchment)
Primary energy	24.5 GJ	48,637	1,191,607 GJ
GWP	10.034 t. CO_2-e	48,637	488,024 tonnes CO_2-e
Eutrophication potential	38 kg PO_4-e	48,637	1848 tonnes PO_4-e
Acidification potential	88 kg SO_2-e	48,637	4280 tonnes SO_2-e
Pesticide use	1.3 dose	48,637	63228 dose
Abiotic Resource use	21 kg Sb-e	48,637	1021 tonnes Sb-e
Land use	0.93 Hectares	48,637	45232 ha
Nitrogen losses			
NO_3-N to water	46 kg	48,637	2237 tonnes NO_3-N
N_2O-N to air	5.6 kg	48,637	272 tonnes N_2O-N
NH_3-N to air	39 kg	48,637	1896 tonnes NH_3-N
Other Emissions			
CO_2 (total) to air	1,544 kg	48,637	75,095 tonnes CO_2
CH_4 to air	228 kg	48,637	11,089 tonnes CH_4
PO_4-P to water	0.5 kg	48,637	24 tonnes PO_4-P

1 gigajoule(GJ) = 1000 megajoules (MJ)

The burdens are generally lower for the FH2020 scenario than for the baseline period. This is due in large measure to the restructuring of the bovine herd i.e. more dairy cows, fewer suckler cows. On balance the FH2020 targets appear sustainable for beef production in the catchment with the structural changes that are proposed in this study.

6.2 Environmental Impact of Sheep Meat Production in the Boyne Catchment

The production system is exclusively lowland as the area has very little upland terrain and no mountainous terrain. The majority of prime lambs produced in the area are born in spring and finished, mainly on grass, during the grazing season. There are two sub-systems – early lamb production and mid-season lamb production. Ewes are generally housed for a period before and after lambing to facilitate better management of the flock. This also prevents attacks by dogs on ewes and their lambs. Housing also prevents attacks on lambs by predators like foxes and other vermin. The system practiced in the catchment is almost identical to lowland sheep production in the UK, which is corroboration of the suitability of the Cranfield LCA model for the environmental systems analysis. Cross bred ewes are generally used by commercial producers (as opposed to pedigree breeders) as hybrid vigour enhances commercially valuable traits associated with fertility and viability. The crossbreds involve a multiplicity of breeds. Rams are normally of pure bred pedigree genotype.

Target for Food Harvest 2020

The target for increased output in FH2020 is a 20% increase in output. However there is no volume increase specified. Accordingly, in this study, it is assumed that a product price increase will be sufficient to meet the output target and sheep numbers are held constant at 91,408 ewes between the baseline and year 2020. It is further assumed that technical and economic efficiency factors remain unchanged over the period. Despite the considerable body of research undertaken, sheep farming remains a very traditional activity.

One of the key indicators of efficiency and profitability in fat lamb production is the number of lambs weaned per ewe put to the ram (Keady and Hanrahan, 2006). In the catchment this indicator is estimated at 1.3 lambs per ewe.

6.2.1 Modelling Sheep Meat Production in the Catchment

The functional unit is defined as 1000 kg of lamb carcass.

As there is an assumption of no change in activity data and no change in technical performance from the baseline to year 2020, and the Cranfield LCA model is deterministic, one run of the model is deemed sufficient to determine the environmental impacts and resources used for baseline and year 2020.

Table 6.2.1: Key input variables for modelling sheep production

Model input variable	Model default value	Alternative value
Proportion of ewes on lowland	37%	100
Proportion of ewes early spring lamb	10%	20%
Change in ewe longevity, yrs	4.5	5.5
Change Killing out percentage	0%	0%

Table. 6.2.2: Technical Parameters (per ewe unit) of Lowland Sheep Production Model

System	**Lowland spring lamb production**	**Lowland early lamb production**
Ewe Flock life, years (replacement rate)	4.5	4.5
Rams	0.0083	0.0083
Gimmers (1-2 year old ewes)	0.28	0.28
Sheep concentrates consumption, kg	53	53
Lamb concentrates consumption, kg	12	97
Grass grazed, kg DM/year	504	502
Hay/ big bale silage, kg DM	190	190
Energy, diesel, MJ	59	59
Mean weight of ewes, kg	80	80
Implied fecundity, lambs/ewe	1.51	1.46
Barren ewes	0.05	0.05
Ewe mortality	0.02	0.02
Culled ewes, head	0.210	0.210
Culled rams	0.0083	0.0083
Store lambs, 26-30 kg lwt – in situ	0.010	0
Store lambs, 30-36 kg lwt – in situ	0.320	0.150
Store lambs, 26-30 kg lwt	0.01	0
Store lambs, 30-36 kg lwt	0.19	0.05
Finished standard lambs (25.5 -32 kg)	0.98	1.26
Wool, kg	3.12	3.12
N_2O, g [N]	13.0	13.0
NH_3, kg [N]	1.39	1.39
CH_4, kg	10.43	10.43
Farmyard manure (FYM), kg	150	500

Higher concentrates for both ewes and lambs are apparent in the early spring lamb system. This is a consequence of a longer housing period with more intensive rearing. Also apparent is the more uniform growth rates in the early lambing system compared with the grass based mainstream production, where there is evidence of a wide range of differential in growth rates.

Table 6.2.3: Output Values: Average Environmental Burdens and Impacts/ tonne of carcass (Functional Unit)

Impacts and resources used	**Average values for baseline period and year 2020**
Primary energy used [MJ] 1000 kg carcass^{-1}	26,792
GWP (100 yrs)[kg CO_2 equiv] 1000 kg carcass^{-1}	13,289
Eutrophication Potential [kg PO_4 equiv] 1000 kg carcass^{-1}	69
Acidification Potential [kg SO_2 equiv] 1000 kg carcass^{-1}	95
Pesticide Use [dose-ha] 1000 kg carcass^{-1}	1.4
Abiotic Resource Use [kg Sb equiv] 1000 kg carcass^{-1}	17
Land Use [site class 4 hectares] 1000 kg carcass^{-1}	3.8
Nitrogen Losses	
NO_3-N to water [kg per 1000kg carcass]	114
N_2O-N to air [kg per 1000 kg carcass]	10.2
NH_3-N to air [kg per 1000 kg carcass]	41
Other Emissions	
PO_4-P to water [kg per 1000 kg carcass]	0.5
CO_2 (total) to air [kg per 1000 kg carcass]	1,703
CH_4 to air [kg per 1000 kg carcass]	255

Primary Energy Use

This is similar to the energy required to produce a functional unit of milk. It is within the expected range. There is considerable scope within the sector to use grass-clover swards for biological nitrogen fixation. The consequent reduction in fertilizer use would reduce upstream energy use for fertilizer manufacture. Like other farm sectors, sheep farmers have opportunities for on-farm production of some of their energy requirements. With some downstream processing, sheep wool produces an excellent fibre for attic insulation.

Global Warming Potential

This is in line with expectation and is low by international standards.

Increased use of grass-clover swards for biological nitrogen fixation would significantly lower nitrous oxide emission from pasture, thereby lowering the GWP per tonne of product.

Eutrophication Potential

This is in line with expectation for the catchment. Low use of nitrogen fertilizer N per hectare associated with sheep production is reflected in low losses of nitrate to water.

Acidification Potential

This is within the expected range. Emission of ammonia (the main driver of acidification) to air is low when compared with other livestock production systems. Accordingly, the need for mitigation within this sector is not a priority.

Pesticide Use

This is in line with expectations. Sheep are prone to attack by a wide range of parasites and diseases. Liver fluke is common and has to be prevented by use of the appropriate biocides. Sheep have to be dipped in an organophosphate solution as a preventative against the sheep scab ecto-parasite. Dosing against a range of intestinal parasites is common practice. A combined vaccination against eight clostridial diseases is routine.

Abiotic Resource Use

The result is in line with expectation. Plastic containers for animal health products can readily be recycled. Copper sulphate is used for foot baths. Cobalt and Selenium are used as nutritional elements. There is no critical issue regarding the depletion of natural resources.

Land Use

The value of 3.8 hectares per functional unit is in line with expectation for the Boyne Catchment area. Extensive use of grassland by light weight animals is expected to be sustainable in the long term from a land use perspective.

Scaling up from functional unit to total sheep meat production in catchment

The average number of ewes in the catchment during the baseline period was 91,408 producing an average of 118,830 fat lambs per year. For the purpose of this study it is assumed that these production figures will remain unchanged in 2020.

It is assumed that 50 lamb carcasses yield 1000kg of meat (i.e. 1 Functional Unit). In the case of culled ewes it is assumed that 40 carcasses yield 1000 kg of mutton. Total sheep meat output for the catchment is estimated at 2763 tonnes (functional units). The outputs from the Cranfield LCA model are scaled from functional unit to total sheep meat produced in the catchment. The results are presented in Table 6.2.4.

Table 6.2.4: Environmental burdens for total sheep meat produced in catchment

Environmental Impacts and resources used	**Model output values per functional unit (FU)**	**Total FUs catchment**	**Total impact/ resource use for sheep meat production (catchment)**
Primary energy	27GJ	2793	75,411 GJ
GWP	13.289 t. CO_2-e	2793	37,116 tonnes CO_2-e
Eutrophication Potential	69 kg PO_4-e	2793	193 tonnes PO_4-e
Acidification Potential	95 kg SO_2-e	2793	265 tonnes SO_2-e
Pesticide Use	1.4 dose-ha	2793	3910 dose-ha
Abiotic Resource Use	17 kg Sb-e	2793	47.5 tonnes Sb-e
Land Use	3.8 Hectares	2793	10,613 hectares
Nitrogen losses			
NO_3-N to water	114 kg	2793	318 tonnes NO_3-N
N_2O-N to air	10.2 kg	2793	28 tonnes N_2O-N
NH_3-N to air	41 kg	2793	114 tonnes NH_3-N
Other emissions			
PO_4-P to water	0.5 kg	2793	1.4 tonnes PO_4-P
CO_2 (total) to air	1,703 kg	2793	4756 tonnes CO_2
CH_4 to air	255 kg	2793	712 tonnes CH_4

Inference from the model results: In general environmental burdens are low in the sheep sector and as the intensity of production remains unchanged from baseline to year 2020, the FH2020 scenario appears very sustainable.

6.3 Environmental impact of Beef Production in the Boyne Catchment

The Food Harvest 2020 programme calls for an increase in output of 20% although there is not a volume increase specified. In view of increasing global demand for beef, it is plausible to assume that almost all of this output can be achieved by a beef price increase of 20%, despite the availability of alternatives to beef.

Raw material for beef production comes in the form of calves from dairy herds and suckler herds. As indicated in the previous section there is an assumption that each extra dairy cow unit is accompanied by a 0.8 cow unit decrease in the suckler herd. A proportion of suckler calves would be replaced by extra calves from the dairy herd leaving a net small decrease in volume output on the beef side. Beef production in combination with milk can be carried out with fewer animals than with the specialist beef cow production system.

There is a multiplicity of beef production/rearing systems used in the Boyne Catchment. The most important of these are set out in the following list:

1. Steer beef of dairy origin finished at 18 months
2. Heifer beef of dairy origin finished at 18 months
3. Steers and heifers from dairy herds finished at 22-24 months
4. Intensive cereal beef (Dairy X dairy bulls) finished at approx. 12 months
5. Intensive cereal beef (Continental X dairy bulls) finished at approx. 13 mts.
6. Silage beef (dairy and continental X bulls) finished at 16-17 months
7. Autumn calving suckler herds
8. Spring calving suckler herds
9. Winter feeding spring-born suckled calves
10. Grass finishing spring-born suckler stores
11. Winter finished suckled calves
12. Intensive cereal beef – spring born calves (suckler bulls)
13. Silage beef (suckler bulls and steers)

6.3.1 Modelling beef production in the catchment

The beef model is a synthesis of the systems listed above. Estimates of the proportions in the different classes are used for inputs into the model. In this case also the functional unit is 1000 kg of carcass meat. This standardisation enables comparisons to be made with other meat products for environmental impact and resource use. It further enables hotspot issues to be identified. Beef production with calves of dairy origin is parameterised in Table 6.3.1

Table 6.3.1: Systems of Dairy Beef Production (Calf to Beef) and associated parameters

Parameter	**18-20 months beef (Male)**	**18-20 months beef (Female)**	**22-24 months beef**	**Cereal beef (dairy X dairy bulls), 11-12 months**	**Cereal beef (continental X dairy bulls), 12-13 months**	**Silage beef (dairy & continental X bulls) 16-17 months**
Calf mortality	3.0%	3.0%	3.0%	2.6%	2.6%	2.6
Killing out %	55%	54%	55%	53%	54%	54%
Weeks weaning to finish	82.8	82.8	100.2	57	54.5	71.9
Mean transport distance	100 km	100 km	100 km	100 km	100 km	100 km
Grazing, kg DM	1165	1197	1618	0	0	0
Entrance liveweight, kg	45	45	45	45	45	45
Slaughter LWT, kg	565	510	600	535	575	575
Average LWT	336	305	355	319	341	341
Milk replacer, kg	15	15	15	15	15	15
Calf ration, kg	160	160	160	160	160	160
Finishing ration, kg	403	414	560	0	0	0
Rearing ration, kg	372	382	517	0	0	0
Barley ration, kg	0	0	0	2225	2039	991
Hay, kg	30	30	30	120	120	30
Silage, kg DM	1059	1088	1471	0	0	1867
Days reared to finished	489	489	610	308	291	412
Daily gain kg/day	0.93	0.82	0.80	1.38	1.60	1.13
Proportion conc. fed	28%	28%	28%	100%	100%	40%
Calf weight in	110	110	110	110	110	110

Beef production of suckler cow origin is parameterised in Table 6.3.2

Table 6.3.2: Systems of Suckler Beef Poduction with associated parameters

Parameter	**Suckler herds – autumn calving**	**Suckler herds- spring calving**	**Winter feeding spring-born suckled calves**	**Grass finishing spring-born suckler stores**	**Winter finished suckled calves**	**Cereal beef – spring born calves (Suckler bulls)**	**Silage beef (suckler bulls and steers)**
Cow mortality	1.0%	1.0%					
Calf mortality	2.5%	2.5%	1.5%	0.7%	0.3%	2.6%	2.6%
Cow mature LWT, kg	550	550					
Killing out %				55%	55%	55%	55%
Productive life, yrs	7.5	8.0					
Weeks	52	52	25.7	24.5	28.0	26.5	34.3
Avg transport distance			100	100	100	100	100
Grazing, kg DM	2411	1673	0	1211	0	0	0
Entrance LWT, kg	40	40	275	385	365	278	278
Exit LWT, kg	365	275	385				
Slaughter LWT, kg/hd				565	595	575	560
Average LWT, kg	176	137	330	504	509	452	444
Calf concentrates, kg	150	100					
Finishing conc., kg				127	540	0	892
Cow conc., kg	216	128					
Rearing conc., kg			279				
Barley ration, kg						1494	
Hay, kg	230	250				90	
Silage, kg DM	1148	1495	611		1184		1053
Days reared to finish	296	213	180	172	196	186	240
Daily gain, kg/day	1.08	1.08	0.61	1.05	1.17	1.59	1.17
Proportion conc. feed	10%	7%	35%	10%	35%	100%	50%
Calf weight in	45	45	275	275	275	280	280

Implementation of the Beef Model

Some of the default variables were changed to more accurately represent the patterns of beef production in the target area – the Boyne Catchment. These changes for the baseline period are presented in Table 6.3.3. The values are based on available data and expert opinion and are believed to be a close approximation beef production in the catchment area.

Table 6.3.3: Key Variables for inputs to model beef production in the baseline period

Parameter	Default Value	Alternative Value
Beef calves reared from Sucklers	50%	79%
Proportion of dairy beef finished intensively (cereal or silage beef)	45%	10%
Proportion of dairy beef finished 22-24 months (versus 18-20 months)	25%	80%
Proportion of dairy X dairy calves (versus dairy X beef)	39%	36%
Proportion of spring born sucklers	33%	80%
Proportion of spring born suckler calves finished as cereal beef	14%	8%
Proportion of spring born suckler calves finished as silage beef	14%	8

The model outputs for the baseline period, based on the above inputs and parameters, are presented in Table 6.3.4

Table 6.3.4: Output Values: Average Environmental Burdens and Impacts/ tonne carcass for baseline period

Impacts and resources used	Average Values for 2007-2009
Primary energy used [MJ] tonne carcass^{-1}	31 [GJ]
GWP(100yrs)[kg CO_2 equiv] tonne carcass^{-1}	14,661 kg
Eutrophication Potential [kg PO_4 equiv] tonne carcass^{-1}	90 kg
Acidification Potential [kg SO_2 equiv] tonne carcass^{-1}	172 kg
Pesticide Use [dose-ha]tonne carcass^{-1}	1.4 dose
Abiotic Resource Use [kg Sb equiv] tonne carcass^{-1}	18 kg
Land Use [hectares] tonne carcass^{-1}	2.28 ha
Nitrogen Losses	
NO_3 –N to water [kg] tonne carcass beef^{-1}	131 kg
N_2O-N to air [kg] tonne carcass beef^{-1}	10.9 kg
NH_3-N to air [kg] tonne carcass^{-1}	79 kg
Other Emissions	
CO_2 total to air [kg] tonne carcass^{-1}	1,879 kg
CH_4 to air [kg] tonne carcass^{-1}	294 kg
PO4-P to water [kg] tonne carcass^{-1}	0.5 kg

Primary Energy

This is very high usage of energy. It is 9% higher than the value per functional unit for sheep meat. It is 20% higher per functional unit than in the case of dairying. Energy consumption at all stages of agricultural production contributes to global warming as well as consumption of non-renewable resources (fossil fuels).

Global Warming Potential

This is high relative to milk production but fifth lowest in the EU27 (Liep et al, 2012). The dominance of suckler beef production in the catchment is reflected in a high value for GWP_{100}. A restructuring of the cow herd suggested in this study would lead to a significant lowering of the GWP per tonne of product.

Eutrophication Potential

The emission of phosphate to water is low (0.2 $kgha^{-1}$). This is less than half that of the amount lost to water from the typical dairy farm. It reflects the extensive nature of beef production. The emission of NO_3^- to water is moderate (57 kg ha^{-1}). This is a reflection of the low-moderate use of nitrogen fertilizer on beef production farms. Typically, the vast majority of specialist beef farms would be compliant with the organic nitrogen limits of the Nitrates Directive. However, on farms where beef is combined with intensive dairying compliance with some of the conditions of the Directive may be more challenging.

Acidification Potential

This value of this environmental impact is in line with expectation

Pesticide Use

This value is in line with expectation. A range of agro-chemicals is used in beef production. These include biocides for the control of parasitic organisms that are similar to those used in dairying.

Abiotic Resource Use

This value is in line with expectation.

Land Use

In general beef production is less intensive than dairying and so uses more land.

Scaling up from functional unit to total beef production in the catchment (baseline period)

The killing out percentage of beef was assumed to average 55% of the liveweight of the animal at slaughter. It was assumed that, during the baseline period, the average finished beef animal weighed approximately 605 kg prior to slaughter. Accordingly, the functional unit (1000Kg) represents approximately 3 beef carcases. After making allowance for exported calves and suckler stores, the baseline estimate for average finished beef animals per annum in the catchment is 89,135. This amounts to 29,711 tonnes of carcass beef (functional units).

Table 6.3.5: Average Environmental burdens of total beef production in the catchment during baseline period

Environmental Impacts and resources used	**Model output values per functional unit (FU)**	**Total FUs**	**Total impact/ resource use for beef production (catchment)**
Primary energy	31 GJ	29,711	921,041 GJ
GWP	14.661 t. CO_2-e	29,711	435,593 tonnes CO_2-e
Eutrophication potential	90 kg PO_4-e	29,711	2674 tonnes PO_4-e
Acidification potential	172 kg SO_2-e	29,711	5110 tonnes SO_2-e
Pesticide use	1.4 dose	29,711	41595 dose
Abiotic Resource use	18 kg Sb-e	29711	535 tonnes Sb-e
Land use	2.28 Hectares	29711	67741 ha
Nitrogen losses			
NO_3-N to water	131 kg	29,711	3892 tonnes NO_3-N
N_2O-N to air	10.9 kg	29,711	324 tonnes N_2O-N
NH_3-N to air	79 kg	29,711	2347 tonnes NH_3-N
Other Emissions			
CO_2 (total) to air	1,879kg	29,711	55827 tonnes CO_2
CH_4 to air	294 kg	29,711	8735 tonnes CH_4
PO_4-P to water	0.5 kg	29,711	14.8 tonnes

Change in Beef Production for 2020

An increase in dairy cows of 13,057 will provide an estimated extra 6000 calves for beef production. A decrease in suckler cow numbers at the rate of 0.8 cow units for each dairy cow unit increase would yield a loss of 10,445 sucklers with an implied loss of 9,400 suckler calves. The estimated net loss of calves to the beef system is therefore 3,400 calves.

Table 6.3.6: Key Variables for inputs to model beef production for year 2020

Parameter	**Default Value**	**Alternative Value**
Beef calves reared from Sucklers	50%	45%
Proportion of dairy beef finished intensively (cereal or silage beef)	45%	40%
Proportion of dairy beef finished 22-24 months (versus 18-20 months)	25%	25%
Proportion of dairy X dairy calves (versus dairy X beef)	39%	42%
Proportion of spring born sucklers	33%	30%
Proportion of spring born suckler calves finished as cereal beef	14%	15%
Proportion of spring born suckler calves finished as silage beef	14%	15%

The inputs in Table 6.3.6 represent a change in the pattern of beef production in the catchment – a shift from dependence on suckler beef towards more dairy beef to reflect the increase in dairy cow population. There is also a trend towards slaughtering at lighter weights at lower ages.

Table 6.3.7: Output Values: Average Environmental Burdens and Impacts/ tonne carcass for year 2020

Impacts and resources used	**Average Values for year 2020**
Primary energy used [GJ] tonne carcass^{-1}	31 [GJ]
GWP(100yrs)[kg CO_2 equiv] tonne carcass^{-1}	12,328
Eutrophication Potential [kg PO_4 equiv] tonne carcass^{-1}	77
Acidification Potential [kg SO_2 equiv] tonne carcass^{-1}	148
Pesticide Use [dose-ha]tonne carcass^{-1}	2.2
Abiotic Resource Use [kg Sb equiv] tonne carcass^{-1}	18
Land Use [hectares] tonne carcass^{-1}	1.87
Nitrogen Losses	
NO_3 –N to water [kg] tonne carcass beef^{-1}	108
N_2O-N to air [kg] tonne carcass beef^{-1}	8.7
NH_3-N to air [kg] tonne carcass^{-1}	67
Other Emissions	
CO_2 total to air [kg] tonne carcass^{-1}	1,868
CH_4 to air [kg] tonne carcass^{-1}	245
PO4-P to water [kg] tonne carcass^{-1}	0.9

Comparison of impacts and resource use between baseline and year 2020

Primary Energy Use

Primary energy use per functional unit produced remains largely unchanged for this resource. Although dairy cows have extra energy requirements associated with milking and cooling of milk, nevertheless the dual purpose nature of the animals compared to sucklers means that replacement of some sucker cows leads to a reduction in energy for cow maintenance.

Global Warming Potential (GWP)

This impact is substantially reduced reflecting the reduction in sucker cows and their replacement with the more efficient dual-purpose (milk and beef) dairy cows.

Eutrophication Potential

This impact is also reduced by the changes in the system. This should have a beneficial effect on water quality in the catchment and make the objectives of the Water Framework Directive more attainable. However, predictions (Humphreys et al., 2009) suggest that rehabilitation of aquatic ecosystems following eutrophication takes a long time. Evidence from Lough Sheelin (not part of the Boyne Catchment) shows that recovery times can run into decades (Kerins et al, 2007).

Acidification Potential

Again this impact is reduced by the system changes. This would also be a desirable development.

Pesticide Usage

As expected, this burden has increased significantly. This is partly due to increased use of animal health biocides (e.g. antibiotics). Dairy cows have to be treated for endo and ecto parasites. Milking equipment and bulk storage tanks also require substantial use of detergent-sterilizers.

Land Use

The system changes from the baseline years to FH2020 result in substantial reduction in land use. A partial shift from suckler beef to dairy beef leads to a more efficient use of this resource. Suckler beef production is an inefficient user of land due to the need to maintain a cow for every calf produced without getting the benefit of any co-product. This change from the baseline to 2020 frees up more land for other uses. This could, for example, be used to grow bio-energy crops or to provide ecosystem services.

Nitrogen Losses

Nitrate-N to Water

In the FH2020 scenario, emission of nitrate to water is lower per unit of product but higher per hectare (57 kg ha^{-1}) used. This reflects the higher use of nitrogen fertilizer commonly associated with dairy farms. Specialist beef farms usually have low inputs of fertilizer.

Nitrous Oxide to air

There is a significant reduction in this emission per unit of product associated with the FH2020 scenario. This has beneficial implications for the climate change balance sheet.

Ammonia to air

Ammonia emissions per unit of product are reduced in the FH2020 scenario. This has the potential to reduce (indirectly) a number of environmental impacts.

Other Emissions

Carbon dioxide to air

Emission of CO_2 per unit of product is almost identical for FH2020 and the average of the baseline years.

Methane to air

As anticipated, CH_4 emissions were reduced in the FH2020 scenario. A change that has 50% of dairy beef calves reared as bulls rather than steers would result in a substantial reduction of CH_4 for the animals concerned (Dawson *et al.*, 2009,). Furthermore, more intensive feeding at earlier slaughter and at lower weights would also lead to lower emissions.

Phosphate to water

The emission of PO_4-P associated with FH2020 is higher per unit of product than for the baseline period. Nevertheless, the loss of phosphate per hectare is tolerable and lower than figures sometimes quoted in the literature (Kiely, 2007)

Scaling up from functional unit to total beef production in the catchment (FH2020)

The technical assumptions used for the baseline years are applicable to the FH2020 scenario as well. Killing out percentage is expected to remain unchanged. The reduction in calf numbers resulting from a reduction in suckler cows reduces the potential beef output in the catchment by 1133 tonnes (functional units).

The environmental impacts and resource use of total beef production in the FH2020 scenario are presented in Table 6.3.8.

Table 6.3.8: Average Environmental burdens of total beef production in the catchment during year 2020

Environmental Impacts and resources used	Model output values per functional unit (FU)	Total FUs	Total impact/ resource use for beef production (catchment)
Primary energy [GJ]	31 GJ	28,578	885,918 GJ
GWP	12.328 CO_2-e	28578	352,310 tonnes CO_2-e
Eutrophication potential	77 kg PO_4-e	28578	2201 tonnes PO_4-e
Acidification potential	148 kg SO_2-e	28578	4230 tonnes SO_2-e
Pesticide use	2.2 dose	28578	63,268 dose
Abiotic Resource use	18 kg Sb-e	28578	514 tonnes Sb-e
Land use	1.87 Hectares	28578	53,441 ha
Nitrogen losses		28578	
NO_3-N to water	108 kg	28578	3086 tonnes NO_3-N
N_2O-N to air	8.7 kg	28578	249 tonnes N_2O-N
NH_3-N to air	67 kg	28578	1915 tonnes NH_3-N
Other Emissions		28578	
CO_2 (total) to air	1,868 kg	28578	53,384 tonnes CO_2
CH_4 to air	245 kg	28578	7002 tonnes CH_4
PO_4-P to water	0.9 kg	28578	26 tonnes

Inference: The overall environmental impact and use of resources associated with the beef production component of FH2020 can be sufficiently mitigated by appropriate management strategies that render it a sustainable option.

6.4 Environmental Impact of Pig Production in the Boyne Catchment

Although the number of pig units in the catchment is small (14), the scale of production is very large. The average number of sows during the baseline period was estimated as 7,800. The Food Harvest 2020 blueprint calls for a 50% increase in pig meat output by 2020. The national target is to increase the pig herd from 150,000 to 200,000 with an increase in productivity from 21 pigs per sow to 24 pigs per sow per annum. For the purpose of this study, the increases are applied pro-rata to pig production in the Boyne Catchment. Accordingly the target for 2020 is 10,400 sows producing a total of 218,400 pigs per annum.

Assumptions

The functional unit in this case is 1000 kg of pig carcass weight. The average killing out percentage is 75% and the average weight per pig pre-slaughter is 100 kgs. At the technical performance standards pertaining for the baseline period each sow would deliver 1.575 functional units per annum. The baseline sow herd of 7800 would deliver 12285 functional units (tonnes of carcass meat). The scale and importance of pig production is evident in that its output tonnage of meat is equivalent to 40% of the total beef produced in the catchment.

Table 6.4.1: Technical Parameters used (per sow unit) in the Pig production model

Technical Parameter	**Value**
Breeding Unit	
Sow Mortality, %	3%
Pigs reared per litter, No	9.3
Litters per year, No	2.27
Days piglets in farrowing house per litter	27.5
Concentrates per sow per day in farrowing house, kg	7
Sow productive life, years	2.34
Cull sows inedible, %	34%
Lactating sow concentrates, kg	437
Dry sow concentrates, kg	863
Total sow concentrates, kg	1300
Weaner Rearing Unit	
Time in weaner unit, weeks	6.42
Start liveweight, kg	7.7
Daily gain, kg	0.496
Exit liveweight, kg	30
Mortality, %	5.1%
Feed conversion ratio	1.71
Weaner concentrates, kg	38.1
Finishing Unit	
Time in finishing unit, weeks	15
Start liveweight, kg	30
Exit liveweight, kg	100
Killing out, %	75%
Mortality, %	6.8%
Feed conversion ratio,	2.74
Finisher concentrates, kg	189
Daily gain, kg	0.639

6.4.1 Modelling Pig Meat Production in the Boyne Catchment

Some of the default variables were changed to more accurately reflect pig production systems in the Boyne Catchment. These changes for the baseline period are presented in Table 6.4.2. The values are based on available data and expert opinion and are believed to be a close approximation of pig production in the catchment area. The model categorises exit live weights into light, medium and heavy. The assumption is that all pigs are marketed as medium weight (100 kg).

Table 6.4.2: Key variables for inputs to the pig production model (baseline)

Parameter	Default Value	Alternative Value
Breeding herd outdoors %	33%	0%
Weaner herd outdoors %	25%	0%
Pigmeat market as light %	33%	0%
Pigmeat market as medium %	50%	100%
Pigmeat market as heavy %	17%	0%
Pigmeat as organic %	0.6%	0.6%
Finisher feed conversion ratio	2.74	2.74
Weaner feed conversion ratio	1.71	1.71
Weaner daily gain (g/day)	496	496
Finisher daily gain of medium (cutter) pigs, g/day	639	639
Pigs reared per litter	9.5	9.5

Table 6.4.3: Output Values: Average Environmental Burdens and Impacts/ tonne pig meat carcass for baseline

Impacts and resources used	Average Values for 2007-2009
Primary energy used [MJ] tonne carcass^{-1}	24,526 [MJ]
GWP(100yrs)[kg CO_2 equiv] tonne carcass^{-1}	4,155 kg
Eutrophication Potential [kg PO_4 equiv] tonne carcass^{-1}	35 kg
Acidification Potential [kg SO_2 equiv] tonne carcass^{-1}	101 kg
Pesticide Use [dose-ha]tonne carcass^{-1}	3.3 kg
Abiotic Resource Use [kg Sb equiv] tonne carcass^{-1}	25 kg
Land Use [hectares] tonne carcass^{-1}	0.72 kg
Nitrogen Losses	

NO_3 –N to water [kg] tonne carcass beef^{-1}	31 kg
N_2O-N to air [kg] tonne carcass beef^{-1}	3.1 kg
NH_3-N to air [kg] tonne carcass^{-1}	43 kg
Other Emissions	
CO_2 total to air [kg] tonne carcass^{-1}	1,634 kg
CH_4 to air [kg] tonne carcass^{-1}	37
PO4-P to water [kg] tonne carcass^{-1}	1.1

Primary Energy Use

Primary energy use per functional unit is similar to the value for sheep meat but is 20% lower than for beef production.

Global Warming Potential

From a climate change perspective, McGettigan (2010b) [in Chapter 2] points to the national production of pig meat as having a low carbon intensity compared with other meat production regimes. This is supported by this study which evidenced the comparatively low Global Warming Potential of pig meat in the Boyne Catchment.

Eutrophication Potential

Phosphate emission to water per tonne of product is more than double that of sheep or beef.

One of the critical issues governing the sustainability of any food production system is the impact it has on local water supplies. It is against that background that intensification of pig production in the catchment must be examined for sustainability. The nutrient load (N and P) associated with grass based livestock farming in the catchment is probably sustainable with good nutrient management strategies. However the overall nutrient load is greatly amplified when nutrients from pig units are recycled within the catchment. Pig slurry contains almost twice as much phosphate as cattle slurry. In particular, the total phosphate loading from all enterprises needs to be examined.

Acidification Potential

This is in line with expectation. Ammonia volatilization is associated with storage and land spreading of pig slurry. Although ammonia is a base, as already stated its conversion to other chemical species leads to acidification. Mitigation options for this emission of ammonia will be discussed in Chapter 7.

Pesticide Use

This is higher than for cattle and sheep enterprises but largely in line with expectations. The production of feed grains for pig nutrition is dependent on multiple sprayings with a range of pesticide (plant protection) products.

Abiotic Resource Use

High use of phosphorus in the feed is a concern. Mitigation of this impact is considered elsewhere in the thesis.

Land Use

Land use is lower for pig production than for ruminant meat and dairy milk production. However, the quality of land for production of pig feed is generally superior to that used by ruminants. In this study the land is assumed to be class 3a. Some of the feed (soya) is produced in South America, which is a cause for concern from an ecological point of view, in particular, when land use change involves the growing of Soya on recently deforested land. According to Steinfeld et al(2006), in order to meet the demand for more pig meat, more pig feed will be produced and transported, more deforestation will occur, more slurry will be excreted. Consequently a cascade of polluting activities will be stimulated by the increased demand for pig meat (Dalgaard, 2007)

Scaling up from functional unit to total pig meat produced in catchment (baseline)

The average for total pig meat production in the catchment during the baseline period was estimated as:

Total pigs X 0.1 x 0.75 =21840 X 0.1 X 0.75 = 16,380 tonnes (functional units).

The environmental impact and resource use outputs from the Cranfield LCA model are scaled up from functional unit (FU)-based values to values based on total pig meat production in the catchment. The results are presented in Table 6.4.4

Table 6.4.4: Average Environmental burdens of total pig meat production in the catchment during the baseline years

Environmental Impacts and resources used	**Model output values per functional unit (FU)**	**Total FUs**	**Total impact/ resource use for pig meat production (catchment)**
Primary energy [GJ]	25 GJ	16,380	409,500 GJ
GWP	4.155 tonne CO_2-e	16,380	68,059 tonnes CO_2-e
Eutrophication potential	35 kg PO_4-e	16,380	573 tonnes PO_4-e
Acidification potential	101 kg SO_2-e	16,380	1654 tonnes SO_2-e
Pesticide use	3.3 doses	16,380	54,054 doses
Abiotic Resource use	25 kg Sb-e	16,380	409 tonnes Sb-e
Land use	0.72 ha	16380	11,794 ha

Nitrogen losses			
NO_3-N to water	31 kg	16,380	508 tonnes NO_3-N
N_2O-N to air	3.1kg	16,380	51 tonnes N_2O-N
NH_3-N to air	43 kg	16,380	704 tonnes NH_3-N
Other Emissions			
CO_2 (total) to air	1,634 kg	16,380	26765 tonnes CO_2
CH_4 to air	37 kg	16,380	606 tonnes CH_4
PO_4-P to water	1.1 kg	16,380	18 tonnes

Change in Pig Production for 2020

The Food Harvest 2020 calls for a 50% increase in output of pig meat. This change has a number of components – a one-third increase in sow numbers and increases in productivity per sow. Number of pigs goes from the baseline 21 pigs per sow per annum to 24 pigs per sow per annum. Food conversion ratio per weaner goes from 1.71 to 1.7. Food conversion ratio for finishers improves from 2.74 to 2.70. Average daily liveweight gain for pig progeny is also improved. These improvements are a reflection of relentless genetic progress that is a feature of pig breeding . These key variables relevant to the increase in output are presented in Table 6.4.5.

Table 6.4.5: Key variables for inputs to pig model for 2020

Parameter	Default Value	Alternative Value
Breeding herd outdoors %	33%	0%
Weaner herd outdoors %	25%	0%
Pigmeat market as light %	33%	0%
Pigmeat market as medium %	50%	100%
Pigmeat market as heavy %	17%	0%
Pigmeat as organic %	0.6%	0.6%
Finisher feed conversion ratio	2.74	2.70
Weaner feed conversion ratio	1.71	1.70
Weaner daily gain (g/day)	496	500
Finisher daily gain of medium (cutter) pigs, g/day	639	650
Pigs reared per litter	9.5	10.35
Litters per sow per year	2.27	2.32

Running the pig model with the input data shown above gives the environmental impacts per functional unit shown in Table 6.4.6

Table 6.4.6: Average Environmental Burdens and Impacts per tonne of carcass (functional unit) in 2020

Impacts and resources used	**Average Values for 2020**
Primary energy used [GJ] tonne carcass^{-1}	23.845 GJ
GWP(100yrs)[kg CO_2 equiv] tonne carcass^{-1}	4.042 kg
Eutrophication Potential [kg PO_4 equiv] tonne carcass^{-1}	34 kg
Acidification Potential [kg SO_2 equiv] tonne carcass^{-1}	99 kg
Pesticide Use [dose-ha]tonne carcass^{-1}	3.2 kg
Abiotic Resource Use [kg Sb equiv] tonne carcass^{-1}	24 kg
Land Use [hectares] tonne carcass^{-1}	0.71 ha
Nitrogen Losses	
NO_3 –N to water [kg] tonne carcass^{-1}	30 kg
N_2O-N to air [kg] tonne carcass^{-1}	3.0 kg
NH_3-N to air [kg] tonne carcass^{-1}	42 kg
Other Emissions	
CO_2 total to air [kg] tonne carcass^{-1}	1,588
CH_4 to air [kg] tonne carcass^{-1}	36
PO4-P to water [kg] tonne carcass^{-1}	1.1

Primary Energy Usage

This impact per functional unit is slightly reduced for 2020 relative to the baseline average.

GWP

This is also slightly lower for 2020 relative to the baseline. More efficient production leads to lower GWP per unit of product.

Eutrophication Potential

This value per functional unit is similar for baseline and 2020.

Acidification Potential

This impact is similar for baseline and 2020.

Abiotic Resource Use

This impact is similar for baseline and 2020.

Land Use

This remains unchanged from baseline to 2020

Scaling up environmental impacts from Functional Unit (FU)-based values to values based on total catchment production

Projected output for 2020 is 24,570 functional units (tonnes of carcass). Total environmental impacts and resource use for 2020 are presented in table 6.4.7

Table 6.4.7: Average Environmental burdens of total pig meat production in the catchment during 2020

Environmental Impacts and resources used	Model output values per functional unit (FU)	Total FUs	Total impact/ resource use for pig meat production (catchment)
Primary energy [GJ]	25 GJ	24,570	614,250 GJ
GWP	4.155 tonne CO_2-e	24,570	102,088 tonnes CO_2-e
Eutrophication potential	35 kg PO_4-e	24,570	860 tonnes PO_4-e
Acidification potential	101 kg SO_2-e	24,570	2,482 tonnes SO_2-e
Pesticide use	3.3 doses	24,570	8,1081 doses
Abiotic Resource use	25 kg Sb-e	24,570	614 tonnes Sb-e
Land use	0.72 ha	24,570	1,7690 ha
Nitrogen losses			
NO_3-N to water	31 kg	24,570	762 tonnes NO_3-N
N_2O-N to air	3.1kg	24,570	76 tonnes N_2O-N
NH_3-N to air	43 kg	24,570	1057 tonnes NH_3-N
Other Emissions			
CO_2 (total) to air	1,634 kg	24,570	40,147 tonnes CO_2
CH_4 to air	37 kg	24,570	909 tonnes CH_4
PO_4-P to water	1.1 kg	24,570	27 tonnes PO_4-P

It must be borne in mind that the pig meat targets represent an extra layer of loading on top of the normal burden associated with ruminant livestock production in the catchment. The nitrogen emissions (Table 6.4.7) are particularly onerous and mitigation measures must be considered in Chapter 7.

6.5 Effects of the FH 2020 Livestock Plan on the Environment of the Catchment

The overall changes in impacts associated with FH2020 are presented in Table 6.4.8. Sheep is not represented in the table as the assumption is that environmental burdens associated with the species do not change under FH2020. Activity data and technical performance for sheep are assumed to remain unchanged.

Table 6.4.8: Changes in Impacts resulting from Food Harvest 2020 Plan

Change in Impact (+/-)	**Milk Production**	**Beef**	**Pigs**	**Net Change [+/-] with FH 2020**
Primary Energy Use	+329,369 GJ	-35,123 GJ	+204,750 GJ	+498,996 GJ
Global Warming Potential	+134,938 t. CO_2-e	-83,283 t. CO_2-e	+34,029 t. CO_2-e	+85684 tonnes CO_2-e
Eutrophication Potential	+521 t. PO_4-e	-473 t. PO_4-e	+287 t. PO_4-e	+335 tonnes PO_4-e
Acidification Potential	+1163 t. SO_2-e	-880 t. SO_2-e	+828 t. SO_2-e	+1111 tonnes SO_2-e
Pesticide Use	+26749 dose	+21,673 doses	+27027 doses	+75,449 doses
Abiotic Resource Use	+948 t. Sb-e	-21 t. Sb-e	+205 t. Sb-e	1132 tonnes Sb-e
Land Use	+5436 ha	-14,300 ha	+5896 ha	-2968 hectares
Nitrogen Losses				
NO_3-N to water	+546 t. NO_3-N	-806 t. NO_3-N	+254 t. NO_3-N	-6 tonnes NO_3-N
N_2O-N to air	+73 t. N_2O-N	-75 t. N_2O-N	+25 t. N_2O-N	+ 23 tonnes N_2O-N
NH_3-N to air	+503 t. NH_3-N	-432 t. NH_3-N	+353t. NH_3-N	+424 tonnes NH_3-N
Other Emissions				
CO_2 (total) to air	+20,873 t. CO_2	-2443 t. CO_2	+13,382 t. CO_2	+31812 t. CO_2
CH_4 to air	+3097 t. CH_4	-1733 t. CH_4	+303 t.	+1667 t. CH_4
PO_4-P to water	+10.7 t. PO_{4-P}	-11.2 t. PO_4-P	+9 t. PO_4-P	8.5 tonnes PO_4-P

6.5.1 Consequences of intensification of livestock production in FH2020

The changes in environmental impacts resulting from the intensification embedded in Food Harvest 2020 are summarised as percentages in Table 6.4.9

Table 6.4.9: Consequences of intensifying livestock systems (FH2020)

Environmental Impact Category	Change resulting from FH2020
Primary Energy	Increase of 23%
Global Warming Potential (100 years)	Increase of 10%
Eutrophication Potential	Increase of 7%
Acidification Potential	Increase of 11%
Pesticide Use	Increase of 57%
Abiotic Resource Use	Increase of 28%
Land Use	Increase of 2.5%

Replacing a proportion of suckler cows with dairy cows has had a very significant impact. Furthermore, the total quantity of beef produced in the catchment has been reduced by 1,133 funtional units (which must be produced elsewhere outside of the catchment), in the process, freeing up 2968 hectares of land for alternative use in the growing of forage maize for dairy herd expansion. Despite this adjustment, however, Primary Energy Use and Global Warming Potential still stand out as environmental hotspots.

Eutrophication Potential

The increase in eutrophication potential associated with intensification of livestock production is 7%. The increase may not seem large in the overall scheme of things but any increase is undesirable and is ominous from the point of view of achieving and sustaining "Good" water status under the Water Framework Directive. As mentioned in Chapter 3, there is a history of water quality problems in the Blackwater Catchment where most of the pig production is concentrated.

Other Impacts

Focusing on individual chemical species, the loss of Nitrogen by volatilisation of NH_3 is significantly increased (by 424 tonnes). Since ammonia volatilization contributes (indirectly) to GWP, EP and AP, mitigation measures must be examined as a matter of urgency. This is an issue that will be tackled in Chapter 7.

Each of the greenhouse gases (CO_2, CH_4 and N_2O) is significantly higher with the FH2020 scenario.

Pesticide use has increased by a substantial 57% due to changes in the livestock sector alone, although coming from a low base. The scope of this study does not permit a forensic examination of this increase.

Abiotic Resource use is increased by 28% although this is an impact that should be addressed on a more global scale.

Land Use is reasonably well balanced in the FH2020 scenario.

Individual impact categories will be examined in the next chapter (Chapter 7) with a view towards mitigation of negative issues identified for the environment.

Chapter 7

Mitigation Strategies for Impact Categories and Resource Uses

7.1 Mitigation Strategies:

The environmental hotspots associated with Food Harvest 2020 were identified and assessed in Chapters 5 and 6.

The main goal of this chapter is to explore environmental improvement options relevant to the impact categories that have been examined in the study. What pollution prevention strategies and environmental management systems are necessary for the sustainable delivery of the targets involved in Food Harvest 2020?

Objective 1: Reduced use of fossil energy footprint and generation of renewables from local sources.

Objective 2: Lower carbon footprints for main farm enterprises in the catchment.

Objective 3: Lower levels of nutrient enrichment of surface and ground water resources.

Objective 4: Reduced level of acidifying pollution emitted from farms.

Objective 5: Efficient and safe pesticide use.

Objective 6: Efficient abiotic resource use and recycling strategies that reduce mineral resource depletion.

Objective 7: Efficient and sustainable land use.

7.1.1 Primary Energy Use as an impact category: possible mitigation measures

The model outputs indicate that there is a large increase in primary energy use associated with implementation of the Food Harvest 2020 programme. The net increase attributable to the livestock sector is almost 500,000 GJ. The hotspot enterprises are milk production and pig production.

Energy use on farms

In this study, energy use on farms has been examined as an environmental impact. As well as consumers of energy, farmers have significant opportunities to generate energy from farm produced materials. Possible ways of saving energy in the production systems also need to be examined. It is important to draw a distinction between primary energy and secondary energy (the so-called energy carriers).

Energy use on farms is an environmental impact where substantial progress towards mitigation can be made. Depending on the range of enterprises, there are options when it comes to producing and saving energy on farms. Simple, cost effective measures like insulation of the dwelling house can yield substantial savings in usage of energy carriers (either fossil fuel or renewables).

Energy use in Dairy Farming

The modelling result identified dairy farming in the catchment as a hotspot of primary energy use. The net increase in energy use resulting from the Food Harvest 2020 target was +329,369 GJ.

In what ways can energy savings be made on dairy farms?

The literature review has identified milk cooling and water heating as major energy users in the form of electricity. A Teagasc survey of electrical energy usage on 21 commercial dairy farms during 2010 indicated that there is a large range in energy costs, from 0.23 cent per litre of milk produced to 0.76 cent per litre. In terms of actual power consumption the range was 53 to 108 watts per litre of milk produced. The most efficient producer was able to halve the consumption of electricity compared with the least efficient producer.

Energy Usage for Water Heating

Adequate quantities of water are critical to the production of high quality milk standards on dairy farms. Hot water is used in conjunction with detergents and sterilizers to clean milking systems and refrigerated bulk storage tanks for milk. Failure to have water available at the right temperature and in the right quantity leads on to increase in bacterial contamination and failure to reach the required milk quality standard. The volume of hot water required varies between farms and is directly related to the number of milking units, milk pipeline diameter and lengths and the presence of a range of system accessories (e.g. receivers, recording jars or electronic milk meters, automatic cluster removers etc.). As a general rule, the minimum hot water requirement is 9 litres at 80^oC per milking unit for each hot wash cycle plus a reserve for bulk tank washing. At the Moorepark Dairy Research Centre, Teagasc compared two methods of providing hot water. In the study 500 litres were heated from 14^oC to 80^oC with a 3kW immersion heater element and a 26.4 kW oil fired burner using kerosene. The results are given in Table 7.1.

Table 7.1: Effect of heating system on the cost and carbon footprint of heating water

Heating Method	Power consumned KW.h	Rated Power kW	Heating Time (hrs.)	Cost per 100L Night Rate / Day rate (€)	Kg CO_2 produced / 100L
Electricity	48.24	3	16.5	0.88 / 1.80	6.23
Oil	45.5 (4.4 L Kerosene)	26.4	1.75	0.85	3.03

Source: Teagasc, Moorepark (Upton et al., 2010)

Whilst the cost of water heating was similar between night rate electricity and kerosene fuel, the Global Warming Potentials were dramatically different. GWP for the oil fired heating system was less than half that that of the electrically heated water. From a climate change perspective, electric water heating has a higher impact, and is therefore less desirable, than oil-fired systems.

Energy Usage for Milk Cooling

Milk cooling on dairy farms is a high user of energy. The usual milk cooling system found on farms is a two-stage process, pre-cooling and refrigeration. The technology has changed little in the past 3 decades but operational efficiency has improved. Pre-cooling is achieved by passing the milk that has come from the cow (at 38^{o}C) through a Plate Heat Exchanger (PHE) before it is pumped into the bulk tank. The heat exchange is accomplished by pumping cold water through the opposite side of the PHE. The cold water absorbs some of the heat, thus pre-cooling the milk. The goal of pre-cooling is to lower the milk temperature, bringing it as close as possible to the temperature of the water. The cooler the water supply is, the more effective the pre-cooling would be. The Teagasc Energy Use on Farms document (Upton et al., 2010) points to a number of advantages associated with pre-cooling of milk using wells or mains water supplies. These include:

1. Economy – cooling costs can be reduced by about 50% depending on the temperature and volume of water and the operational efficiency of the cooler.
2. Global Warming Potential - Reduced energy expended on milk cooling means reduced carbon footprint.
3. Milk quality – pre cooling enables a lower milk blend temperature (i.e difference between cooled milk from the previous milking and the warmer milk entering the tank from the current milking). This helps curtail the growth of bacteria in the tank.
4. The tepid water from the pre-cooler can be used for udder washing, yard washing and drinking water for stock.
5. Pre-cooling milk will reduce cooling times when compared with otherwise identical systems without pre-cooling.

Mandatory Targets for Renewable Energy

Under EU Directive 2009/2//EC, Ireland has been set a legally binding target for the share of renewable consumption by 2020. The target is 16% overall, which must be met across the electricity, heat and transport sectors.

The National Renewable Energy Action Plan (NREAP), submitted to the European Commission in July 2010, sets out the strategy for attainment of the 16% overall target for renewables. The sectoral requirements are: 10% renewable energy in the transport sector, 12% in the heat sector and 40% in the electricity sector. The full achievement of the three sectoral targets is in line with the delivery of the legally binding 16% overall target.

In the case of electricity the target is challenging. At the end of 2010, consumption of electricity from renewable sources was just 14.8% . There is a substantial gap to be bridged to deliver the target of 40% renewable electrical energy by 2020. It is estimated that meeting the 2020 target will require an installed renewable generating capacity of approximately 4,000 MW (SEAI, 2011).

Options for energy generation

Farmers are consumers of energy but, unlike other consumers, they can also be producers of renewable energy in various forms e.g. growing of biomass crops, combustion of biomass, growing oilseed rape as a raw material for liquid bio-fuels, wind turbines, etc.

Producing heat from biomass on farms

Burning of wood logs from trees grown on the farm for heating the farmhouse has been (and remains) a commonplace, sustainable, activity. A wide range of combustion devices are used, from simple open fires to sophisticated microprocessor controlled burners.

The next step is for the farmer to consider if there are biomass feedstocks on the farm that could be used to fire the boiler. If feedstocks other than wood are available, then a multifuel boiler that can burn other materials should be considered. Biomass crops that can be grown on farms include the following:

Cereal Grains

Oats burn more easily than other cereals. However the food versus fuel controversy arises whenever edible crops are used as a feedstock for energy production. In reality the issue can be distilled down to the opportunity cost of land use rather than the “burning of food” per se. An unpalatable low yielding type of oat called black oats has been used instead of the common yellow oat crops. However farmers growing oats for use in their own boilers could use the higher yielding main stream varieties of oats. Grain moisture content should be reduced to 15% or less for safe storage and good combustion. For comparative purposes, approximately 2 acres of oats would heat an average sized farmhouse,

Straw as a biomass fuel

Arable farmers sometimes find it difficult to find a financially rewarding outlet for straw. Straw from cereals, rape and bean crops can, however, be burned in suitable boilers in a range of bale sizes. In thermal energy terms rape straw has the highest calorific value. Barley straw is slightly more valuable than oat straw. Wheat straw, from a thermal energy point of view, is the least valuable. Weather at harvest time is critical. Ideally, straw should be left on the ground for a number of days prior to baling. It is important that the straw is dry at the time of baling and the bale tension should be adjusted downwards to make low-medium density bales. High density bales do not burn very well. The bales should be removed from the field and stored in a shed. Following combustion the ash from the boiler can be spread on the land to recycle the mineral nutrients contained therein. A new power station at Rhode in County Offaly will provide an outlet for straw as well as Willow and Miscanthus.

Farm Forestry

Wood material from farm woodlands /forestry can be used for combustion. The trees are either chipped or cut into logs. Where woodchip is the final product form, the wood should first be seasoned before chipping. Cutting trees into logs will speed up the seasoning process. Farmers with forestry plantations can take out first thinnings about 12-15 years after planting, if thinning is advised as a management practice. As an alternative to mainstream (sawlog) timber production, farmers could consider using part of their land for forestry to provide heating for the dwelling house and other heat usage on the farm that could be provided by burning biomass. Whilst conventional forestry takes a long time to mature (45 years for conifers), short rotation forestry can provide wood biomass in a shorter time frame.

Biomass Energy Crops

The growing of biomass energy can to a significant degree displace fossil fuels associated with energy usage and GHG emissions from high environmental impact farm enterprises. The biomass energy crops were not subjected to environmental LCA analysis in this study.

Miscanthus

Miscanthus can be grown as a perennial biomass crop. It is harvested on an annual basis to provide an income stream. It does not reach peak yield of biomass until the fourth year after planting. Part of the biomass may be utilised for heat production (replacing fossil fuel) on the farm e.g. for heating the farmhouse or drying grain after harvest. Miscanthus can be chipped and burned in suitable wood chip boilers. Miscanthus can also be handled in bales and burned in boiler systems capable of burning straw bales. Harvesting is usually done with a modified self-propelled forage harvester. Miscanthus production is marginal in the Boyne Catchment. Salix is viewed as a more viable biomass crop.

Willow (Salix)

Willow is another perennial biomass cash crop. Some of the biomass may be burned on the farm, as a replacement for fossil fuel, to provide heat, for example, for the dwelling house or drying grain on arable farms. The standing crop has typically a moisture content of 55% which is too high for combustion. Two methods of harvesting are possible. The whole stems may be harvested and left to season before chipping. Alternatively, willow stems can be chipped by a modified forage harvester. The chips must be dried to less than 25% moisture before being used. Teagasc have developed a low-cost method of drying the chipped material. A clamp of willow chips is ventilated with ambient air for 12 hours a day for a period of 3 months. This costs in the region of €5 per tonne. Willow chips are a suitable feedstock for wood chip boilers. Baling of the willow biomass material is also an option as it can be utilized in some boilers that can handle straw bales. Yield from an experimental plot at Teagasc Oakpark was 14 tonnes per hectare in Spring 2013.

Table 7.2: Energy Value Comparisons (Biomass versus Fossil Fuels)

Fuel	Energy Density GJ/t (kWh/ t.)
Log wood air dry 20% MC	15 (4170)
Wood chip 20% MC	15.2 (4225)
Wood pellets	18 (5004)
Grain	16 (4448)
Miscanthus (bale)	17 (4726)
Coal (lignite-antracite)	20-30 (5560-8340)
Heating Oil	42 (11,676)
Natural Gas	54 (15,012)

Source: Teagasc

Biomass products at similar moisture content generally have similar energy density values.

Liquid Biofuels

The main crop grown for liquid biofuel is oil seed rape. It is profitable for growers but it is not clear if a viable and sustainable industry can be set up in this country for processing the crop into biodiesel. The likely scenario is that the oil seeds produced here will continue be sent to the UK for processing. The mandatory requirement for renewable inclusion is likely to be attained by importing bio-diesel to blend with fossil diesel. Importation of bio-ethanol to blend with fossil-derived petrol is another likely strategy for achievement of the 2020 target for renewable energy in the transport sector.

Energy Produced from Anaerobic Digestion (AD) of Farm Produced Materials

Biogas (mainly methane) can be produced under controlled conditions by fermenting a range of feedstock materials. These materials can be food waste, animal slurry, biomass (e.g. grass or maize) grown specifically for biogas production. In the case where slurry is the feedstock, anaerobic digestion process is a physical treatment that accelerates a naturally occurring process. Methane is released from manure naturally in storage, particularly when stored for long periods in open storage tanks. However, for efficient capture of methane, the slurry needs to be transferred to the digester within 2-4 weeks of being produced by livestock.

An experimental digester has been set up in Boyne Catchment at Teagasc Centre, Grange, Co. Meath. It will take time for the relevance of this technology for the Boyne Catchment to be examined in detail.

What is the possible relevance of Anaerobic Digester (AD) technology in energy production at farm level in the catchment?

The capital costs of anaerobic digesters and ancillary equipment are prohibitive for individual farmers. The technology involved is much more complex than the production of energy by combustion of biomass. If AD is to have a future it must be in centralised units with feedstock from many local farms.

Energy produced by Abiotic non-farm sourced resources

As previously mentioned in this section, dairy farms have substantial daily requirements for hot water (>80^{o}C) to enable cleaning and sterilization of milking and milk storage facilities. It is therefore appropriate to examine the feasibility of using solar panel technology to replace at least some of the electricity or fossil fuels used for this purpose. Solar panels convert solar radiation to thermal energy which is then available to heat water.

The surface area of solar panels for heating water in a dairy unit depends on the amount of hot water required to wash the milking machine and bulk tank. For this purpose the temperature needs to be in the range 80-85^{o}C. However, domestic scale solar systems are limited to 65^{o}C, so there is a heat deficit to be bridged, which requires a booster system to lift the temperature by an extra 15-20 degrees. The solar collectors are connected to highly insulated buffer tanks with capacity 1.5 times the daily water requirement. A 10 unit milking parlour requires 130-150 litres of hot water daily. The large buffer tank allows more water to be heated on sunny days, which is stored to balance out fluctuations in solar energy reaching the solar collectors. The tanks are insulated to a standard that allows a drop of only 1^{o}C per day. Future technical developments in the solar energy sector will undoubtedly have applications in reducing the dependence of fossil-fuel-derived energy usage on farms.

Wind Energy

Farmers have a big part to play in the wind energy sector by provision of sites for wind farms. Whilst the costs of large wind turbines and ancillaries would be prohibitive for farmers, they can lease the land to large energy providers.

7.1.2 Global Warming Potential as an impact category: possible mitigation measures

The model output identified GWP as a hotspot for dairy farming in the catchment. The increase in GWP associated with delivery of the milk production element of Food Harvest 2020 was 134,938 tonnes of CO_2 equivalent. The increase in GWP associated with the projected increase in pig meat output for FH2020 is much lower than for dairying at 34,029 tonnes at CO_2 equivalent. Although pig production in Ireland (and the Boyne Catchment) had not previously been subjected to an impact analysis for GWP (using LCA methodology), there are results from Denmark which indicate that the most significant contributors to global warming potential are nitrous oxide (44%), methane (32%) and carbon dioxide (20%). The Danish study found that feed consumed by pigs was the most significant environmental hotspot.

The abatement measures available for reduction of GHG emissions fall into three broad categories:

1. Reduction of the emission intensity of agricultural production in the target area.
2. Offsetting emissions associated with agricultural production by carbon sequestration.

3. Displacement of fossil fuel through production of biofuel and bioenergy crops. The options for farm-produced materials are explored under the “Primary Energy Use” impact category.

Reduction of GHG emission intensity

Donnelan (2012) has predicted a 17% increase in fertilizer N use by 2020 if the targets of FH2020 are to be met. This is unsustainable and incompatible with the EU Climate and Energy Package (CEC, 2007), where a 20% reduction in emissions from the non-ETS sector is required by 2020. More innovative approaches to the use of Nitrogen will be required.

There is evidence that farmers have become less profligate in the use of nitrogenous fertilizer. Higher usage of Nitrogen fertilizer is more common in intensive dairying systems than in beef or sheep systems. Very high levels of Nitrogen fertilizer are no longer possible under Nitrate Directive regulations. Even in cases of derogation from the Directive the maximum amount of fertilizer permitted on grassland is approximately 285 kg ha^{-1} yr^{-1} and is closely related to stocking density on the farm.

Nutrient Management Options: More Efficient Use of Nitrogen

Is substitution (partial replacement) of Nitrogen fertilizer with Nitrogen fixed from clover a realistic option on the grassland farms of the catchment? What would the potential benefits be?

In the scenario of displacement of Nitrogen fertilizer by biologically fixed Nitrogen using clover, the following environmental and economic benefits would appear to arise:

1. Reduction in fossil fuel energy use. Nitrogen fertilizer production uses large amounts of natural gas and can account for more than 50 percent of total energy use in commercial agriculture. Fossil fuel energy requirements for the manufacture of fertilizer N can equate to approximately 60 MJ per kg of N (Woods *et al.*, 2010). At a conservative estimate of 100 kg N per hectare fixed biologically by clover, the potential saving of energy is approximately 6,000 MJ (6 GJ) per hectare of pasture.

2. Reduction in CO_2 emissions. Assuming 100 kg CO_2 emission per GJ fossil energy, it seems a plausible assumption that with biological N fixation a potential emission reduction of 600 kg CO_2 per hectare could arise.
3. Reduction in N_2O emissions. According to De Klein *et al.*(AR4,2006), IPCC no longer estimate N_2O emissions from biological nitrogen fixation as there appears to be no evidence of significant emissions associated with the N-fixation process. Using the IPCC default Emission Factor of 1.25% for applied fertilizer N, a biological fixation of 100 kg N per hectare could potentially reduce N_2O emission by 1.0 Kg per hectare (approximately 320 kg CO_2-equivalent). Significant extra amounts of nitrous oxide are also emitted during the manufacture of nitrate although it is not quantified in this calculation
4. Combining 2 and 3, there is potential emission reduction, associated with biological N fixation, of 920 kg of CO_2-equivalent per hectare.
5. Cost reduction where very substantially reduced quantities of fertilizer need to be purchased. Nitrogen fertilizer is subject to substantial price volatility.

Dairying with Grass-Clover swards.

Humpreys and Lawless (2008) did an economic comparison of two systems of dairy production with identical stocking densities of 2.2 cows per hectare, fairly typical stocking density for specialist dairy farming in the Boyne Catchment. In the clover-grass system fertilizer Nitrogen was restricted to 90 kg ha^{-1} yr^{-1}. On the grass only system, fertilizer was increased to 225 kg $ha^{-1}yr^{-1}$. From a financial point of view, the main difference between the two systems was related to the extra cost of fertilizer. The net margin was €9,000 better on a 50 hectare farm with the grass-clover system. With spring calving cows being fed 0.5 tonnes concentrate supplements per cow, the grass-clover based system delivered milk production of 14 tonnes per ha. (Humphreys *et al.*, 2006).

A further comparison was carried out between the grass-clover system and a system using the maximum permissible amount of N fertilizer (285 kgN per ha) and stocked at 2.5 cows per ha. Both systems produced approximately the same net margin on a 50 ha farm. If the grass-clover system produces the same net income with fewer livestock numbers, there are significant advantages from an environmental impacts point of view. Less N cycling within the system would be expected to deliver benefits in lower nutrient loading, leading to improved water quality. Lower use of Nitrogen fertilizer would also be expected lower the emission of Nitrous Oxide, a significant positive impact on the climate balance sheet. Lower usage of fertilizer means lower use of energy and emissions with the manufacture and distribution of fertilizer. In terms of GWP, Yan *et al.* (2009) carried out an LCA analysis of the two systems' experiment at Teagasc Solohead farm and found significant differences. Compared with the straight grass diet driven by N fertilizer, the grass-clover allied to low fertilizer N delivered a reduction in emission related to fertilizer of 69.7% and an overall reduction in emission of 13.6%.

Alternatives to Grass Silage

Conventional grass based silage requires large inputs of fertilizer Nitrogen in addition to slurry. This sets up the likelihood of large losses of N in environmentally damaging ways, N_2O greenhouse gas emissions and emissions of Nitrate to surface and groundwater.

What are the alternatives?

Forage Maize has a part to play but climatically the Boyne Catchment is marginal and the crop suffers badly in cool wet summers. It is an annual crop so cultivation is required on annual basis. It has a high requirement for Nitrogen but as it is capable of recycling large amounts of slurry, the requirement of fertilizer N per tonne of DM is low.

Red Clover Advantages

Much progress has been made by plant breeders in the development of red clover as a forage species. Red clover offers many benefits to farmers trying to optimise animal performance from home grown forage. As a legume, its ability to capture Nitrogen from the atmosphere is estimated to be about 25 kg N per tonne of forage DM produced. Driven by their own Nitrogen supply, red clover varieties at AFBI, Crossnacreevy, Northern Ireland have averaged 17.5 t. DM per ha over the three year life of the sward. The first year yields were 19 t. DM per ha, followed by 18.2 t. DM in year 2 and 15.2 t. per ha in year three.

Eighty per cent of the annual yields were produced in the first two silage cuts. These are highly impressive results from a low input system but it may be reasonable to assume that yields would be lower under commercial farming conditions.

Red clover also enhances the protein composition in the herbage, a significant economic benefit in an era of soaring prices for dietary protein concentrates like Soya Bean meal. Digestibility of red clover silage is high which encourages increased DM intake and reduces the supplementation required from energy based cereals like wheat and barley. The dietary characteristics of red clover improve liveweight gains and milk yields and milk composition relative to feeding straight grass based silage (Meehan and Gilliland, 2012).

Management of Red Clover Swards

There is a number of management issues (some of them challenging) with red clover that do not arise with straightforward grass swards.

Care has to be taken not to graze too closely or to poach the sward as the solitary red clover crown could be damaged either directly or indirectly by compaction. With this in mind, heavy soils with impeded drainage would not be well suited to red clover.

Sheep should not be kept on farms where red clover is grown as the oestrogen content of the herbage would be likely to interfere with breeding and lead to low conception rates.

The lower dry matter content of red clover and high buffering capacity means that it is not as easy to get good preservation as with ryegrass or ryegrass/white clover swards. Wilting in the field for too long could lead to leaf shatter losses if not done correctly.

Red clover can be grown as a monoculture, though it is more commonly grown with Italian/hybrid grasses. The first silage cut is taken at the early flower bud stage in mid-to-late May. The second cut is taken by late July or early August. The aftermath growth can be grazed off. Grazing encourages branching from the crown and improves sward persistence. As a general rule, the grazing interval should not be less than 30 days.

Red clover is not going to be a replacement for permanent pastures of ryegrass/white clover as the bedrock of forage production on the farms of the Boyne Catchment. It can, however, feature in the production of high yields of quality silage with minimal inputs, reducing the fertilizer costs and lowering the carbon footprint and other environmental burdens. Swards should last for three years before renewal if properly managed. Plant breeders are attempting to bring more persistent cultivars on stream that would lengthen the useful life of the sward.

What else can be done to promote efficient recycling of Nitrogen?

Grazing livestock only retain a small proportion of the N ingested with grazed grass. Typically, dairy cows will retain only 25% of dietary nitrogen. Beef animals retain about 10% and sheep retain just 7%. The remainder is excreted on to the pasture mainly in the urine. Urine patches can have extremely high concentration of reactive nitrogen. One possible measure to retain this N in the soil is the use of nitrification inhibitors.

Use of Nitrification inhibitors

These products have the potential to retain nitrogen in the ammonium form – following spreading of slurry or fertilizer N and the deposition of dung and urine from grazing animals.

Nitrification is a biological process that is mediated in the soil by the microorganisms Nitrosomonas and Nitrobacter. The net effect is the conversion of ammonium ions ($NH_4^{+)}$ to Nitrate ions (NO_3^-). Nitrate is readily taken up by plants but its presence also sets up the potential for loss on N in environmentally damaging ways e.g. loss of nitrate to surface and ground water and emission of the greenhouse gas N_2O following denitrification. Retention of nitrogen in the ammonium form would allow plants to take up the nutrient and reduce the environmental impacts.

Nitrification inhibitors are small organic molecules that block or reduce the conversion of ammonium to nitrate. Research work in New Zealand points to significant benefits from the use of nitrification inhibitors. Two potential environmental benefits would be reduction of leaching on porous, free draining soils and reduction of nitrous oxide emissions from the heavier soils (Cameron and Di, 2004). Nitrification inhibitors increase Nitrogen uptake by plants by slowing down the rate at which ammonium is converted to the more mobile nitrate. This opens up the possibility of less wastage of Nitrogen and a reduced usage of nitrogen for any given stocking rate in grazing livestock production systems.

Management of soils and fertilizer for lower emissions

Research at AFBI, Northern Ireland (2009) has shown that N_2O emissions can be reduced by

a) Reducing inorganic fertilizer inputs
b) Avoid spreading nitrate-containing inorganic fertilizer in wet conditions
c) Spreading slurry at least three days before applying N fertilizer
d) Using trailing shoe for slurry applications
e) Inclusion of clover in grass swards

Organic Production Systems

Organic production systems have the potential to deliver low environmental impacts across a range of impact categories. The main drawback is that, for most of the livestock and crop enterprises that pertain to the catchment, almost double the amount of land is required per tonne of product. Modelling of organic production systems was not undertaken in this study because of the low proportion of farms operating in the sector.

Beef Production based on Bull Beef as opposed to steers

In the beef production sector, steer beef farmed extensively has been associated with high levels of methane emission per tonne of product. Research at AFBI in Hillsborough has revealed that beef cattle reared as bulls (rather than steers) and slaughtered at younger ages and lower weights have global warming potentials per tonne of product about 50% of the value for steer beef.

7.1.3 Eutrophication Potential as an impact category: possible mitigation options

The model output estimates an additional net increase in eutrophication potential of 335 tonnes PO_4-equivalent associated with delivery of the livestock targets in the Food Harvest 2020 programme. The hotspot enterprises are milk production and pig production. The projected increase in pig production would contribute an additional 287 tonnes PO_4-

equivalent to total eutrophication potential. This is a substantial nutrient loading on top of the normal cattle and sheep burdens. It must be borne in mind that pig production is mainly concentrated in an area of the Blackwater catchment upstream from Kells, where there has been a history of water quality problems.

What can be done to mitigate the nutrient load associated with pig production?

Phytate (also called inositol phosphate) is an organic chemical form of Phosphorus that is common in feed grains e.g. maize, wheat and soya bean meal. Ruminant animals (e.g. sheep and bovines) have the microbial population in the rumen to convert phytate into a usable inorganic form. Pigs and poultry, on the other hand are monogastric animals and do not have the enzyme (phytase) to convert the phytate-P form in the feed grains into the inorganic Phosphate form which can be absorbed in the digestive tract. Most of the phytate-P passes out in the urine and faeces and, accordingly, dietary supplementation with inorganic P forms (like monocalcium phosphate, dicalcium phosphate or deflourinated phosphate) is employed to supply P in a bioavailable form.

Inorganic Phosphorus Feed : Compostion and Production

Monocalciumphosphate(MCP) is generally used as an inorganic phosphorus dietary source in Irish pig production. An approximate mean value would be 22.7% P (Nielsen and Wezel, 2007). MCP can be produced by treating burnt lime/ chalk (CaO) or $Ca(OH)_2$ with phosphoric acid (H_2PO_4).

Reducing the Phosphorus Nutrient Load in Pig Slurry

Phytase enzymes can be produced by either bacteria or fungi. When used as a feed additive they can strip away inorganic P from the organic phytate (inositol phosphate) molecule (Smith, 2003).

Pig producers can use the enzyme phytase in the diet to reduce the amount of inorganic P needed to be supplemented to the diet to optimize the bioavailability of the key phosphorus nutrient.

The manufacture of Phytase imposes lower environmental burdens than the manufacture of MCP across a range of impact categories.

Life Cycle Analysis of Phytase enzyme versus Monocalciumphosphate (MCP)

In a comparative analysis, Nielsen and Wenzel (2007) did an environmental assessment of Ronozyme (a commercially available phytase product) as an alternative to inorganic Phosphate (monocalcium phosphate, MCP) supplementation to pig feed used in intensive pig production. The LCA model used for the study was Simapro 6.0. The following environmental impact categories were included in the study: global warming, acidification, nutrient enrichment (eutrophication), photochemical ozone formation, primary energy usage, abiotic resource use (rock phosphate), land use.

Results

Characterised environmental impact potentials for the alternative feed ingredients (Ronozyme and MCP) are given in the table below per functional unit of output. The functional unit is 1 kg of either product.

Table 7.3: Comparison of environmental impacts of Ronozyme and Monocalciumphosphate

Impact Category	Ronozyme phytase	MCP	MCP/Ronozyme (ratio)
Global warming (g $CO_{2\ eq.}$)	1,900	32,000	17
Acidification (g $SO_{2\ eq.}$)	4.8	530	110
Nutrient enrichment (g $PO_{4\ eq.}$)	2.2	1,500 (480-21,000)	700(220-9,500)
Photochemical ozone formation, g $C_2H_{2\ eq.}$)	1.5	12	8.0
Rock phosphate, g	0.1	24,000	>240,000
Primary energy, MJ	26	400	15
Agricultural land m^2. Yr^{-1}	0.15	-	-

Source: Nielsen and Wenzel (2007)

The table shows that in general the environmental impacts associated with feed supplementation with Ronozyme Phytase are very low compared with the avoided impacts associated with the displacement of MCP from the feed.

Probable Effectiveness for the Boyne Catchment

Diets supplemented with the phytase additive commonly contain 15 to 25% less total P than diets without that ingredient. There is a reasonable expectation that slurry from pigs which are being fed with the phytase ingredient would have 15 – 25% lower total P load. By reducing the total P in the compounded ration, farmers can reduce the environmental impact on the catchment by reducing the total P excreted by their pigs. This approach should reduce the total amount of P that can potentially be lost to the streams, rivers lakes and the estuary of the catchment. Since most of the pig units are locate in the Bailieborough-Virginia-Mullagh area, the Upper Blackwater and its tributaries, Moynalty River an Yellow River and associated lakes would be likely to benefit by a reduced nutrient loading,

Reduction of the P nutrient loading by the use of phytase in all pig units could potentially reduce the timescale required to reach the Water Framework Directive objective of "Good Water Quality" status.

Phytase use should lead to reduced emission of Phosphorus from intensive pig production in the catchment. This in turn will be likely to contribute to the alleviation of eutrophication pressure on the catchment's aquatic environment.

Another possible option for achieving low emissions of Phosphorus to surface waters within the Catchment is to reduce and maintain low concentrations in the surface layers. Phosphate does not easily migrate down the A horizon of the soil profile and it is mainly concentrated in the top centimetre of soil profile, which facilitates runoff of P during extreme rainfall events. Ploughing and reseeding the fields that have very high soil test P (STP), would be a way of thoroughly mixing the nutrient in the plough layer. Implementation and enforcement of all elements of the Nitrates Directive will be critical to ensure coexistence of commercial farming and water resource protection.

Alternative Use for Pig Slurry

Research in Canada (Cavanagh et al., 2011) has found that pig slurry can be used as an effective fertilizer for willow plantations. Recycling pig slurry in short rotation coppice crops of fast growing willows may constitute an ecological and economical alternative to spreading the manure on grass. Cavanagh et al found that yields measured after two growing seasons on plantations fertilized with slurry are comparable to those obtained for a three-year cycle under similar cultivation and climatic conditions. Since short rotation willow coppice for biomass is a growing enterprise in the Boyne Catchment, this needs to be researched.

7.1.4 Acidification Potential as an impact category: possible mitigation measures

Ammonia volatilisation is the main acidifying influence and, as it is air transported, it may be dispersed long distances from the emission site. As ecosystems mature they develop their own characteristic vegetation in response to local environmental conditions. Nitrogen is often in short supply in natural ecosystems, limiting plant growth and biomass accumulation. Fugitive airborne pollutants (including Nitrogen in reactive forms) from other areas can cast a long environmental shadow, having detrimental effects on sensitive ecosystems. The model outputs show that Ammonia emission is quantitatively high for dairying, beef and pig production within the catchment. As well as being an acidifying influence ammonia volatilisation also represents a loss of N-based plant nutrients from the system. In addition to the acidification associated with NH_3 emissions, there may be other environmental impacts as well. There is the potential for an indirect climate change influence. N directly lost as Ammonia to air has the potential, following chemical transformations, to contribute to N_2O emission. Nitrous Oxide is a powerful greenhouse gas. A multi-stage oxidisation of Ammonia to Nitrate may also lead to eutrophication of surface water and raised levels of nitrate in ground water. The transformations of N following land spreading of slurry are depicted in Figure 7.2.

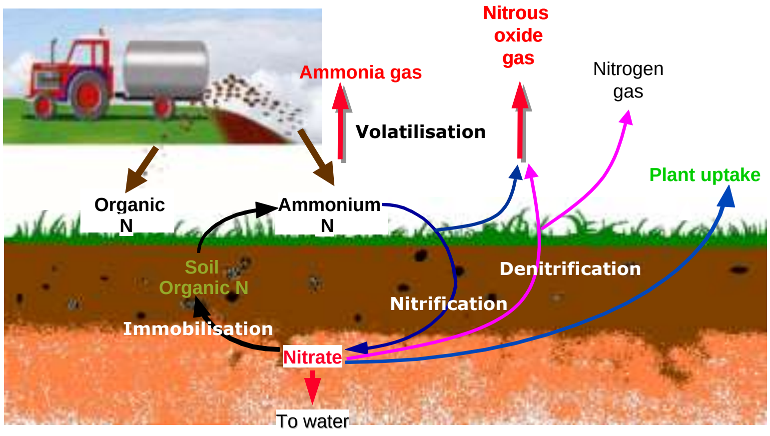


Figure 7.2: Fate of slurry nitrogen following land spreading

Source: DEFRA (2002)

What mitigation measures are possible?

1. Change the method of slurry spreading:

Research by Teagasc (Lalor and Schulte, 2008) and DEFRA (Anon, 2002) has shown that low emission spreading methods can be used to reduce gaseous losses of Ammonia following land spreading of slurry. Replacing the splash plate method with bandspreading, trailing hose, trailing shoe and shallow injection into the soil, have reduced Ammonia emissions. For application to grassland, the trailing shoe is reckoned to be the slurry application method most suitable under Irish conditions. By reducing the losses of Ammonia to air, the N remaining in the soil that is available for crop uptake is increased, thereby resulting in a potential reduction in fertilizer N use and the associated Nitrous Oxide emissions. However, low emission spreading technology is more complex and expensive, with purchasing costs being up to three times more expensive than the simpler splash plate option, Further additional costs would include extra tractor power requirement, lower work rate and increased operating costs. As a result, the economics of low emission spreading technologies restrict their usage to contractors or large scale farmers (Lalor, 2008). Current contractor costs for splash plate application are approximately €50 per hour but the alternative technology costs are likely to be 50% higher.

2. Change the slurry spreading time:

Cooler and moister weather conditions result in lower Ammonia volatilisation. These conditions are more prevalent in spring. Crop uptake of nitrogen is best in spring and where slurry spreading is possible this leads to a reduced need for supplementary fertilizer N. This option may only be possible in moderately-well drained soils which would be the case in about 67% of usable land area of the catchment. In the remaining 33% of the catchment, getting slurry out in wet ground conditions in spring may be problematic in some years. Slurry application to short grass swards in summer is likely to lead to increased ammonia volatilisation losses because of warmer temperatures and reduced slurry infiltration rates into dry soil.

Empirical evidence for method and time of application of cattle slurry

Lalor and Schulte (2009) examined the effects of timing and method of application on the Nitrogen fertilizer replacement value of cattle slurry applied to grassland. Following April application the mean N fertilizer replacement value was 26% and 37% for splash plate and trailing shoe methods respectively. For slurry applied in June the figures were 9% and 18% respectively. Research work at AFBI, Hillsborough, Northern Ireland, found enhanced grass yield, N efficiency and inorganic N savings through the application of slurry using the trailing shoe method as opposed to the splash plate method. The saving in fertilizer N amounted to 44 kg per hectare. A saving in fertilizer of that order equates to a reduction in carbon footprint by 7%.

Because of environmental concerns, there are strong pressures to curb ammonia emissions. The agriculture sector accounts for virtually all Ammonia emissions in Ireland (Hyde *et al.*, 2003). Ammonia emissions increased by 2% between 1990 and 2009. The permitted increase for that period under the National Emission Ceiling was 10%. The maximum emission level permitted under the emission ceiling is 116 kilotonnes (EPA, 2011). Since the ammonia emissions trend is largely determined by the cattle population, it is anticipated that production targets for Food Harvest 2020 would be expected to push emissions well past the National Emission Ceiling.

7.1.5 Pesticide Use as an impact category: possible mitigation measures

One of the main concerns related to the use of pesticides in agriculture is the knock on effects on non-target, often beneficial organisms. It is therefore necessary to identify what the problems are and, as far as possible, to devise methods for their amelioration.

Grass based farming is characterised by very low use of pesticides. In a review of water quality Benoit and Simon (2004) found no evidence in the literature of pesticide contamination under grassland. Nevertheless, grass-based livestock production is not without consequences for insect conservation and diversity. Dung beetles perform an ecological service by assisting the decomposition of dung pats on grazed pastures. Ivermectin is a widely used anthelmintic veterinary medicine and is excreted in the dung of treated livestock in a mainly unmetabolised form. Ivermectin is known to have toxic effects on dung beetles. In recent research, O'Hea et al.(2010) investigated the effect of Ivermectin concentration on various life stages of two Aphodius dung beetle species. They found that larval development rates were significantly slowed by Ivermectin. Ivermectin also had significant negative effects on the survival of larvae. Overall, Ivermectin caused large and significant reductions in the cohort size from an individual dung pat that would potentially contribute to the next generation of beetles. Further research is needed to investigate if an equally effective anthelmintic-type animal health product can be developed without collateral damage to beneficial, non-target organisms.

What about the arable areas of the catchment in relation to pesticide use?

As an alternative to grass silage, forage maize is an important crop in the catchment. It involves greater use of pesticides than grassland (Raison et al., 2006). Late harvesting of maize in the catchment (October, usually) means that ground is left bare over the winter. This means that chemicals could potentially be leached from the soil into the groundwater. The premier herbicide for weed control in maize for decades was Atrazine. This product was banned by the EU in 2007 after health issues related to appearance of the chemical in water. The fungicide benomyl which was widely used in crop production was withdrawn ten years ago after being linked to a number of health problems. In particular, it has recently been shown to be linked to the development of Parkinson's Disease (Fitzmaurice *et al.*, 2013).

Potato crops in the catchment are sprayed up to fifteen times with fungicides for the control of potato blight (Phytophthora infestans). A genetically modified potato with resistance to potato blight is being trialled at Teagasc Oakpark. It is claimed that the GMO variety will have the potential to reduce the chemical load associated with production of the crop.

Pesticide Residues in the Food Chain

Foods of animal origin, such as meat and dairy products, are open to two main sources of potential contamination from pesticide residues. There can be direct application of a pesticide to the animal, for example spraying/dipping with insecticides or consumption of feedstuffs that have been contaminated with pesticides. The two main classes of pesticides have organochlorine (OC) and organophosphorus (OP) active ingredients. The results from tests carried out by Teagasc (National Food Residue Database, 2012) for residues indicate that the common OC and OP pesticides are not a problem in foods of animal origin. It is of the utmost importance to dispose of used dips in a way that does not damage local water

supplies. Farmers using agrochemicals should always have the recommended personal protection equipment. Unused chemicals should be brought for recycling. Chemicals should not be removed from their original containers.
On balance pesticide use has been beneficial when used with appropriate safeguards.

7.1.6 Abiotic Resource Use as an impact category

The modelling output for abiotic resource use in livestock production shows an increase of 1132 tonnes Sb-equivalent associated with the targets for the Food Harvest 2020. The hotspot enterprises are milk production and pig production.

The principle of sustainability implies the use of resources at rates that do not exceed the capacity of the ecosystem to replace them. This interpretation, whilst being strictly correct, does not make reference to the quantity of resources available locally or globally. For examples the Boyne Catchment has resources of limestone far beyond any foreseeable demand in the next few centuries. By contrast, deposits of Phosphate rock are non-existent and there is a requirement for this vitally important mineral to be imported.

Recovery and reuse of P in sewage from all the towns in Boyne Catchment

There are 36 municipal waste water treatment plants (WwTW) in the Boyne Catchment. All but two provide a minimum of secondary treatment. These are point sources of pollution. Their operation represents a eutrophication pressure and also a significant waste of phosphorus which is ultimately flushed out into the Irish Sea, where it is dispersed and irrecoverable. Recovery of P at the treatment works and safe re-use as a nutrient on agricultural land has the following environmental benefits

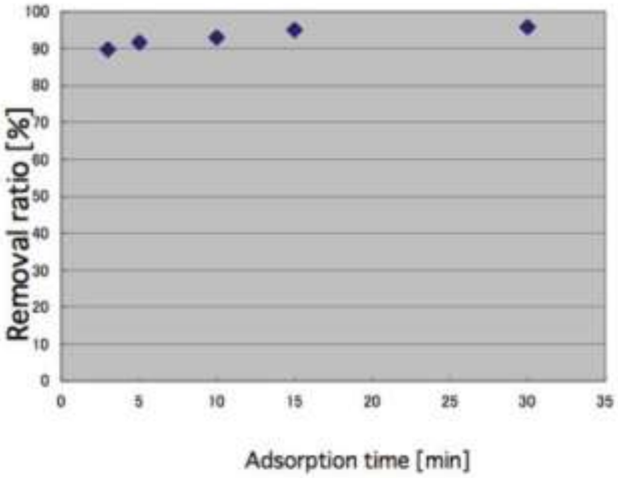
a) Reduction on the nutrient phosphate load and hence the potential for eutrophication
b) Reduction in the quantity of P fertilizer imported into the catchment and conservation of a finite and diminishing resource

In Japan it was found that despite treating effluent to the 1mg/L standard using the advanced wastewater treatment, A_2O, 5-6 tons of Phosphate enter Tokyo bay each day from the treatment plants. This was deemed to be a cause of red tide, resulting in severe damage to the aquatic ecosystem.

Given the damage to aquatic ecosystems by nutrient enrichment and the finite and dwindling availability of high grade rock phosphate and the geopolitical concerns articulated elsewhere (Cordell, 2009), it is unlikely that use of the current phosphate removal technology is sustainable in the long term. In the interests of sustainability, systems that are much more efficient at recovery of P will be required.

Ito *et al.* (2009) studied a new approach to the removal of Phosphorus ions from treated wastewater. They used high grade magnetic separation technology (HGMS) with zirconium ferrite adsorbent to remove the Phosphate from the discharge water. The HGMS with a super conducting magnet has been shown to have two striking benefits. It removes Phosphate to a much greater extent than existing technology and does not generate secondary products or sludge. Recycling of the Phosphate is possible by washing the zirconium ferrite particles in NaOH. Zirconium ferrite adsorbent has ferromagnetic properties when subjected to a magnetic field due to the Fe ions in the ferrite structure. Adsorption rate of the phosphate ions from the liquid sewage to the zirconium ferrite particles is depicted in the graph below. The phosphate removal rate is seen to be dependent on the contact time [mins]. Five minutes of contact time is sufficient to remove more than 90% of the phosphate (i.e. an order of magnitude superior to the currently used methods in the WwTWs of the Boyne Catchment). Longer contact times can provide up to 99% phosphate removal.

Figure 7.3: Adsorption characteristics of zirconium ferrite adsorbent



Source: Ito *et al.* (2009)

Zirconium ferrite $ZrFe_2(OH)_8$ adsorbent has the potential to capture Phosphate in municipal wastewater and facilitate the return (recycling) of P to the terrestrial food chain. Unlike some alternative options, addition of this technology does not require major disruption of existing sewage networks. The technology can eliminate the advanced wastewater treatment process known as A_2O in a sewage treatment plant.

Agricultural Use of Sewage Sludge in Boyne Catchment produced by current available technology

Sewage sludge contains major plant nutrients, phosphate but also nitrogen and potassium. Sustainability would require that crop nutrient elements, P and K in particular, initially derived from finite resources in the lithosphere be returned to the terrestrial food chain. Sewage sludge is available from WwTWs in the Boyne Catchment subject to the regulations. The recycling of sewage sludge on to agricultural land is governed by Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998 [S.I. No. 148/1988].

Maximum application rate for sludge on agricultural land

The maximum amount of sludge which may be applied to land shall be two tonnes of dry matter per hectare per annum.

Heavy Metal content of sludge:

Sludge shall not be used on land where the concentration of one or more heavy metals in the said land exceeds the specified values [see table below], or the use of the sludge may result in the values being exceeded

Table 7.4: Maximum Values for Concentrations of Heavy Metals in Soils

Heavy Metal Element	Maximum Concentration Mg/kg dry matter
Cadmium	1.0
Copper	50
Nickel	30
Lead	50
Zinc	150
Mercury	1.0

Source: Teagasc

Non-Statutory Recommendations

In 2008 the Food Safety Authority of Ireland (FSAI) called for enhanced controls on land spreading of organic materials on land used for food production. The issues associated with land spreading of organic agricultural (OA) and organic municipal and industrial materials (OMI) were highlighted. The report drew attention to gaps in knowledge regarding the transfer of chemical contaminants and pathogens in the food chain through land spreading of OMI materials. The report stated, however, that appropriately managed land spreading of organic waste was a sustainable option when appropriate safety measures were in place. This required the implementation of effective control measures and the consistent application of good practice by all parties involved. The report warned that in the absence of adequate controls, land spreading of organic materials on agricultural land used for food production might pose microbiological and chemical risks to food safety.

7.1.7 Land Use as an impact category: mitigation measures

There is a change in land use from grassland to arable cropping (approximately 3,000 hectares) to accommodate the production of maize silage to support the increased dairy output associated with Food Harvest 2020. There is sufficient suitable land in the catchment to accommodate this changeover. The opportunity cost of the land use change is the foregoing of 1,133 tonnes of beef production which must be transferred out of the catchment.

Whilst there is a (short term) change from sequestration of carbon to emission when the grassland is first cultivated, there is no major concern about the impact of this transition. Most of the GHG emission will be in the form of CO_2. The implementation of a proper nutrient management strategy whereby slurry from livestock farms is recycled back to the maize-growing area is essential. Failure to do this would rapidly lead to the emergence of nutrient imbalances within the catchment and excessive importation of more fertilizers.

7.2 Quantification of mitigation options

It is clear from the contents of this chapter that a significant number of mitigation options are available for the main environmental impact categories. The degree to which these could offset the burdens stemming from the intensification scenarios of Food Harvest 2020 has not been established quantitatively. This would be a suitable task for future research.

A discussion and conclusion of this study is presented in the final chapter.

Chapter 8

Discussion and Conclusion

8.1 Discussion:

The complexities of agricultural production in the Boyne Catchment were examined from a macro environmental perspective. When quantifying the environmental impact of agriculture at regional level, ideally, one would aim for a full LCA approach for all commodities of the agricultural sector. However, this was not feasible because of the complexity and heterogeneity of the sector. The scope of the study is therefore limited to 10 arable crops and 4 livestock production systems. Organic farming was excluded on the basis of the sector being responsible for less than 1% of total output. Production of poultry products were also excluded because of the small scale of the sector.

In contrast to broad perspective of this study, Irish LCA researchers, using small data sets, have usually focused on one enterprise at a time and across one or two impact categories. In a spatial context, no instance has been found in the literature of a wide ranging environmental systems analysis, using LCA methodology, being carried out for a river catchment in Ireland. In two studies, Casey and Holden, using small data sets (15 farms), examined the Global Warming Potential of milk production and suckler beef production. Williams *et al.* (2006) using the Cranfield Model and UK data examined 10 arable crops and 5 livestock production systems (including egg production) across the same range of environmental impact categories used in this study.

At the outset of this project (Page 13), the following research questions were posed:

1. What are the burdens (environmental impacts) associated with the baseline (average 2007, 2008 and 2009) levels of production?
2. What are the burdens (environmental impacts) projected for the levels of output envisaged in the more intensive Food Harvest 2020 plan?
3. What are the increased burdens and are they sustainable?
4. Can the environmental impacts identified be partly mitigated or offset at farm level?

8.2 Extent to which the Research Objectives have been met.

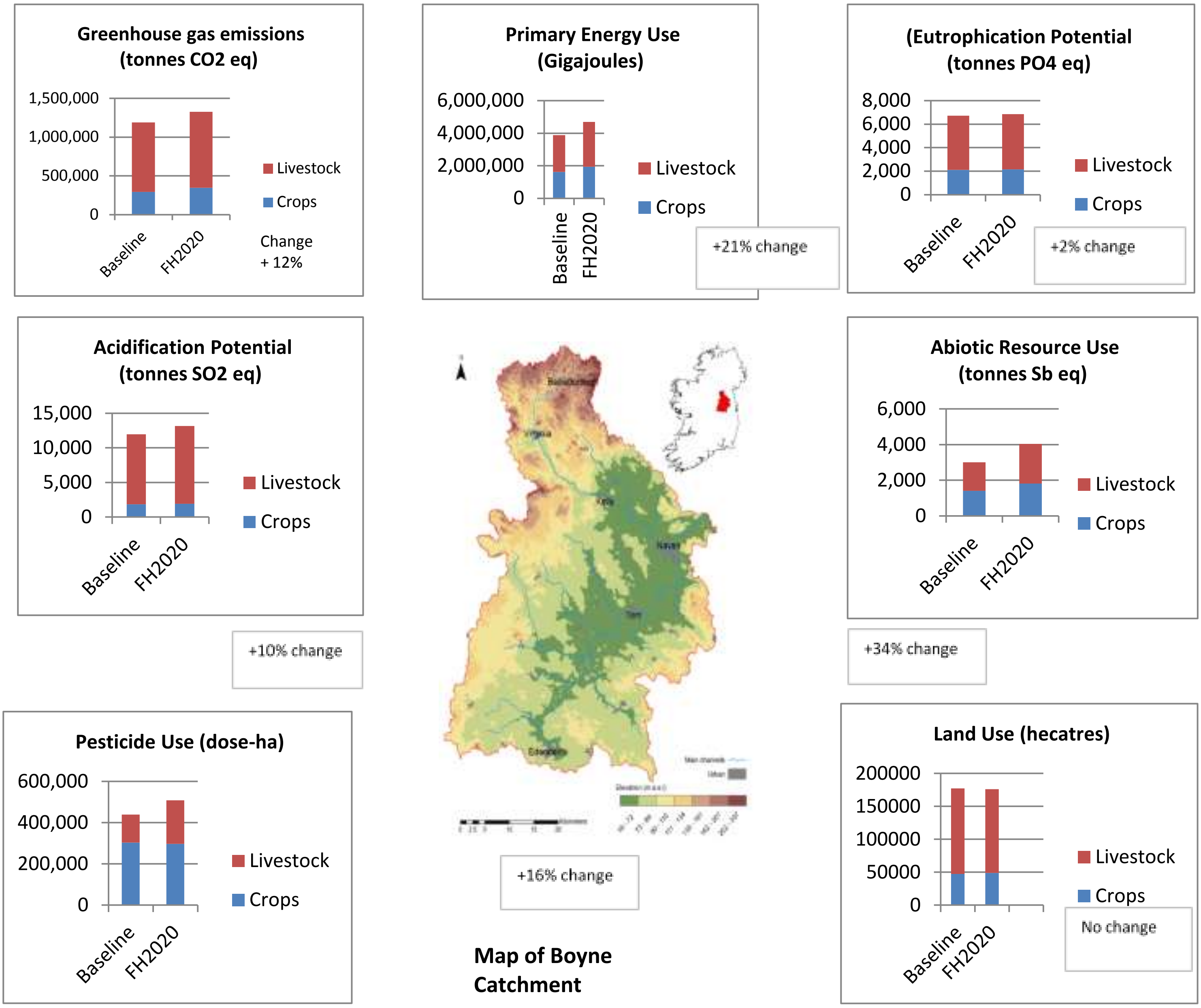
The over-arching objective was to use environmental systems analysis to determine if the Food Harvest 2020 was a sustainable scenario for agricultural production in the Boyne Catchment. In that context the following outcomes were achieved:

1. Generated information on the environmental consequences of implementing the Food Harvest 2020 intensification programme

2. Hotspot issues were flagged in Chapters 5 and 6.

3. The potential for significant mitigation measures at farm level were flagged in Chapter 7.

4. The results provide some guidance for policy and appropriate action plans



Change
+ 12%

+21% change

+2% change

+10% change

+34% change

+16% change

No change

Map of Boyne Catchment

Figure 8.1 Comparison of environmental burdens between Baseline and Food Harvest 2020 scenario

8.3 Changes in environmental impacts emanating from the FH2020 scenario

Figure 8.1 depicts graphically the assessment of seven environmental burdens pre and post intensification.

In the context of the Boyne Catchment the first three of the impact categories (below) are the most critical. The remaining four categories are of somewhat lesser urgency.

8.3.1 Global Warming Potential

The greenhouse gas emissions for arable crops is low relative to animal production systems (Figure 8.1) . In the case of cereals, the GWP is less than 0.5 tonne CO_2-equivalent per tonne of product. There is an overall increase of 51,605 tonnes CO_2-equivalent but this can largely be accounted for by a transfer of 3,000 hectares to the growing of forage maize. The arable component of FH2020 does not cause serious concern for the climate change balance sheet.

Paradoxically, the model outputs show that oilseed rape has a GWP per tonne of product that is more than twice that of cereal crops, field beans and forage maize. However, looking at the full picture, the overall impact of the OSR crop is positive for the climate balance sheet.

In the livestock sector, Irish milk production is seen to have a low GWP per unit of product. The GWP of Irish milk production has been estimated as 40% below the EU-27 average (Liep *et al.*, 2010). Modelling milk production for the Boyne catchment would indicate that GWP per functional unit was 10.647 t. CO_2-e and 10.042 t. CO_2-e for baseline and the FH2020 scenario respectively. However, the increased output envisaged in FH2020 has imposed a substantial increase in gross GWP for milk production in the catchment as a whole.

Although a range of mitigating options have been identified, their potential impact on the GWP balance sheet for the catchment has not been quantified in this study.

The beef structural alterations (suggested in this study) for year 2020, which inter alia envisage the replacement of 10,445 suckler cows with 13,057 dairy cows, resulted in the GWP per tonne of product decreasing from the baseline figure of 14.661 t. CO_2-e to 12.328 t. CO_2-e for the FH2020 scenario. The maintenance costs and environmental burdens of suckler cows are avoided when dairy bred calves enter the beef sector. Although sheep meat and suckler beef have high carbon footprints it should be borne in mind that sucker cows and sheep are capable of producing food from marginal land and thus making a contribution to food security. Marginal land is generally not suited to growing vegetables and cereal grains for human and animal nutrition.

The modelling of pig production yielded a low GWP per tonne of product (approximately one-third of the figure for beef in 2020). However the increased output embedded in the FH2020 plan has added substantially to the gross GWP for the pig sector within the catchment. Again a number of mitigating strategies have been identified but their cumulative potential impact on GWP reduction for the catchment has not been quantified in this study.

8.3.2 Primary Energy Use

In general, the energy usage involved in crop production in the catchment is low. The imposition of Food Harvest 2020 does not raise any serious concern regarding the arable sector. Although, the primary energy usage increases by 325,205 GJ overall, it must be borne in mind that almost 3,000 hectares are transferred from beef production to the growing of forage maize. For most crops, the energy usage per tonne of product is lower for the 2020 scenario than for the baseline period. The model outputs would indicate that about half of the energy usage in arable crop production is attributable to nitrogen fertilizer manufacture. Accordingly, greater emphasis on leguminous nitrogen fixing crops would be highly desirable from an energy efficiency point of view. As mentioned in Chapter 2 the growing of field beans can have an important role in the catchment although some of the crop husbandry is challenging. Potato production has a high energy demand across the production and storage phases. Bio-energy crops and other renewables can offset a proportion of the fossil fuel usage associated with agriculture in the catchment. Oilseed rape is a bio-fuel crop grown in the catchment. Although the extracted quantity of fuel is rather low, the crop also produces a protein residue which is used in animal production as a partial substitute for imported soya bean meal.

Beef production in the catchment has a high energy usage footprint at 31 GJ per tonne of product and it remains high for the FH2020 scenario.

Many farmers within the catchment are well placed to provide a significant proportion of their energy requirements (or could use energy more efficiently in their farming operations). This could start with something as simple as heating the dwelling house using wood and other farm produced biomass materials. This action alone has the potential to replace approximately 2000 litres of kerosene per annum. A wide range of options is explored in Chapter 7. The transfer of low carbon technologies from the research stage to farm level needs to be more actively promoted.

Whilst, as the model outputs verify, energy usage in the livestock production sectors is generally much higher than for crop production, nevertheless there is scope for more efficient use of energy at farm level. On dairy farms possible savings can be made in the areas of water heating and cooling of milk by installation of more efficient systems as set out in Chapter 7 (Upton, 2009). The model outputs for the catchment indicate that, whilst the overall energy footprint is increased, the primary energy usage is generally lowered per unit of product under the FH2020 scenario.

8.3.3 Eutrophication Potential

One of the critical issues governing the sustainability of any food production system is the impact it has on local water supplies. As stated previously, the Blackwater tributary of the Boyne Catchment has a history of poor water quality. It has to borne in mind that there are other eutrifying emission sources apart from agriculture e.g. septic tanks and wastewater from municipal waste water treatment plants.

The aggregate increase in Eutrophication Potential associated with the arable cropping component of FH2020 in the catchment is 38.2 tonnes PO_4-equivalent. Whilst any increase in EP is undesirable, this effect can be offset by improved nutrient management particularly on livestock farms. In particular the recycling of slurry from dairy farms back to the fields on which forage maize had been grown would help to maintain nutrient balance for phosphate.

Pig production by its intensive nature raises concerns about nutrient management – especially Phosphate. The FH2020 scenario of a 50% increase in pig meat output should be accompanied by a compulsory use of the phytase enzyme to increase retention of P by the animal and reduce concentration of P appearing in the slurry.

8.3.4 Acidification Potential

The model outputs indicate that the implementation of the arable cropping component of Food Harvest 2020 would result in increased acidification potential of just 86.6 tonnes of SO_2-equivalent. This is not a cause for concern and can largely be accounted for by fuel-burning operations associated with growing and harvesting an extra 3,000 hectares of forage maize.

In the case of slurry management, the emissions of Ammonia can be substantially reduced by use of appropriate storage and spreading technology, sufficient to offset the impact of increased production under the FH2020 scenario. In additional to its acidifying influence Ammonia emission is an issue under other impact categories as well. Because of the dynamic nature of the nitrogen cycle, Ammonia emission (following transformation in the environment) can instigate fugitive emissions of nitrous oxide and (in the nitrate form) has eutrophication implications as well.

8.3.5 Abiotic Resource Use

The depletion of abiotic non-renewable resources appears to be no more problematic in the Boyne Catchment than anywhere else in the domain of agricultural production. The depletion of Phosphate reserves is a world-wide problem and needs to be tackled on a wider spatial scale with development of better technologies for recycling of this vitally important nutrient. The implementation of FH2020 would not appear to raise any concern under this impact category.

8.3.6 Pesticide Use

The dominance of grassland farming in the Boyne Catchment would lessen concerns about pesticide usage. Grassland management is normally associated with very low levels of pesticide use. In the case of ruminant animal production systems, most of the environmental burden in the pesticide use category is associated with the growing of feed grains for the animals. On balance, there appears to be little or no evidence that use of pesticides in the catchment is a cause for concern, even after implementation of FH2020.

8.3.7 Land Use

The model outputs for the catchment would indicate that sheep meat and beef are the most demanding in terms of area used per tonne of product produced, being 3.8 ha and 2.28 ha respectively. There is a small reduction in these values associated with the implementation of FH2020.

8.4 Final Summary

Whilst seven environmental impacts were modelled for the Food Harvest 2020 scenario, arguably the most urgent and critical issue was climate change. This can be distilled down to the following question: In the implementation of FH2020, could the Boyne Catchment make an important contribution to food security whilst maintaining due diligence with regard to the "two degree" limit for warming that many climate scientists say is needed to avoid catastrophic climate change? Following the findings of this project it could be convincingly argued that "business as usual" is not an option and that the increased agricultural output involved in FH2020 needs to be tied to a package of mitigation measures that are binding, transparent and verifiable. Many of the measures may not be cost neutral and may be hotly contested by farm organisations and other interests within the industry, but, in any case, environmental sustainability should not be diluted to meaningless window dressing.

Finally, in relation to climate change there are some hopeful signs of a willingness to tackle livestock GHG emissions. The Global Research Alliance on agricultural GHGs was launched in 2009. It brings together more than 30 countries to find ways to produce more food without increasing GHG emissions (www.globalresearchalliance.org). In pursuit of this goal, the Alliance promotes active exchange of data, people and research across member countries. As, an exasperated Henry Ford once said to his engineers: *"The reason you have not found a solution is that you have not thought enough about it."*

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