



**MS Dissertation**  
**Economics**

**Economic Dimensions of the Bioeconomy**  
Case Study of Iceland

Elísabet Kemp Stefánsdóttir

Supervisor: Daði Már Kristófersson  
Faculty of Economics  
February 2014



**HÁSKÓLI ÍSLANDS**

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Economic Dimensions of the Bioeconomy. *Case Study of Iceland.*

The dissertation counts for 30 ECTS of a MS degree in Economics from the Faculty of Economics, School of Social Science, University of Iceland.

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Printing: Háskólaprent

Reykjavík, 2014

## **Preface**

This dissertation is handed in as a final qualification for a master's degree in economics from the University of Iceland, and counts for 30 ECTS units. My supervisor for this work was Dr. Daði Már Kristófersson, former associate professor of Economics and current dean of the School of Social Sciences. I would like to thank him for his inspiring guidance and support through out this work. Secondly, I would like to thank my supervisors and co-workers at Matís, Dr. Sveinn Margeirsson, Sigrún Elsa Smáradóttir, Sigríður Sigurðardóttir and many others, for sharing their knowledge and ideas. Thirdly, I want to thank Tim Richardson for his thorough proofreading. Last, but not least, many thanks to family and friends, especially my dear husband, who have shown me nothing but patience and support.

## **Abstract**

The term bioeconomy has attracted increasing attention over the last decade. It is considered to encompass all economic activity connected with the utilisation of renewable biological resources. The renewable biological resources are of particular interest since they offer sustainable utilisation, which ensures non-decreasing welfare for future generations. The objectives with this analysis were to define the bioeconomy, consider the economic dimensions of the bioeconomy, and use these to analyse the Icelandic bioeconomy.

A literary review of the bioeconomy was performed to consider the origin of the term and find a definition. The definition chosen is in synchrony with previous work undertaken by the European Commission and underlines the connection to renewable biological resources. Economic theory was used to propose indicators for the economic dimensions of the bioeconomy, which are value added, part of GDP, labour and capital productivity, exports and part of total export value. The theory of base industries was used to consider if these indicators underestimated the contribution of the bioeconomy to the economy. Principal components analysis and cluster analyses were then used to decide if the economic dimension could be reduced. The analyses indicate that the economic dimension could be reduced to two.

The results show that the bioeconomy in Iceland has a direct contribution of 13% to GDP, where the biggest contribution is from the fishing industry. It has previously been stated that the fishing industry is a base industry in Iceland, and has a total contribution of 26% to GDP. This indicates that the total contribution of the bioeconomy to GDP is around 30%. The Icelandic bioeconomy is a relatively big part of the economy compared to other Nordic countries. The bioeconomies of Iceland, the Faroe Islands and Greenland seem to differ from the bioeconomies of other Nordic countries.

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# 1 Introduction

The world population reached 7 billions in the year 2012 according to estimates from The World Bank and has, in fact, more than doubled over half a century. The growth of the world population and increasing development has created a growing demand for consumption goods. This has created concerns over resource scarcity and the need to manage renewable resources sustainably, in a way that will maximise the utility of current and future generations.

The term bioeconomy has been proposed as a path towards the sustainable management of resources and economic growth. Its origin lies within the OECD and the Seventh Framework Program of the European Commission (OECD, 2009; European Commission, 2012). The definition of the bioeconomy and the goals connected with it are still not clear. The bioeconomy has been mentioned in connection with food security, energy needs and sustainable production for the growing population. Our analysis is concerned with defining what the bioeconomy is, which are its economic dimensions, and using these aspects to evaluate the Icelandic bioeconomy. The research questions we set out to answer are:

- What is the bioeconomy and what are the benefits of considering the bioeconomy separately from other economic activities?
- What are the different economic dimensions of the bioeconomy, how can we measure them and what do the measurements tell us?
- What defines the Icelandic bioeconomy and how big is it?

The paper is built up of nine chapters. In Chapter Two we will go through the background of the bioeconomy, choose a definition of the bioeconomy to work with and consider why the bioeconomy is of interest. We will also go through some of the policy and strategy documents already published on the bioeconomy.

The third chapter introduces economic dimensions connected to the bioeconomy by going through some basic economic theory. We will consider how value creation can be measured, connect it to efficiency and specialisation and introduce sustainability within an economic model. The fourth chapter will introduce a model of base industries. In the

fifth chapter we will go through the statistical methods used later for comparison of the economic dimensions.

In Chapter Six we will go through available data for our analysis of the Icelandic bioeconomy. The seventh chapter will introduce results from our analysis of the Icelandic bioeconomy. Here we will consider three aspects; quantity data of biological resources, sustainability of resource utilisation and economic data related to activity connected with the bioeconomy. We will then conclude if the economic dimensions considered could be reduced, and try to determine which of the Nordic bioeconomies is most similar to the Icelandic bioeconomy.

Chapter Eight will then discuss the analysis; the results found, constraining factors and what should be considered in future work on the bioeconomy. The last chapter will then make concluding remarks on the analysis.

## **2 The bioeconomy**

In this chapter, the bioeconomy concept will be better introduced. Firstly, this will be done by considering the origin of the term and proposing a definition. Secondly, we will introduce some of the policy and strategy proposals already published on a national level.

### **2.1 Definition**

Evolution of the world's economy is driven by technological progress and increased knowledge. With increased knowledge our view of the world changes, and technological progress can help us assess the problems of the world and how we can fix them. At the beginning of the 21<sup>st</sup> century, we have become aware of problems connected with an increasing world population and natural resource scarcity. In order for the human population to survive, we will need to make sure that future populations will at least have food security. It is also preferable that their living conditions should not be worse than ours currently. Thus, we are also concerned that they will have sufficient energy and that the earth's condition will not have decreased significantly.

Sustainable development is a term that was first used in the late 20<sup>th</sup> century. It was supposed to propose a solution to natural resource scarcity. But the definition of sustainable development is not clear. The term has different meanings for different people. The best known definition is from the World Commission on the Environment and Development (1987). They define sustainable development as:

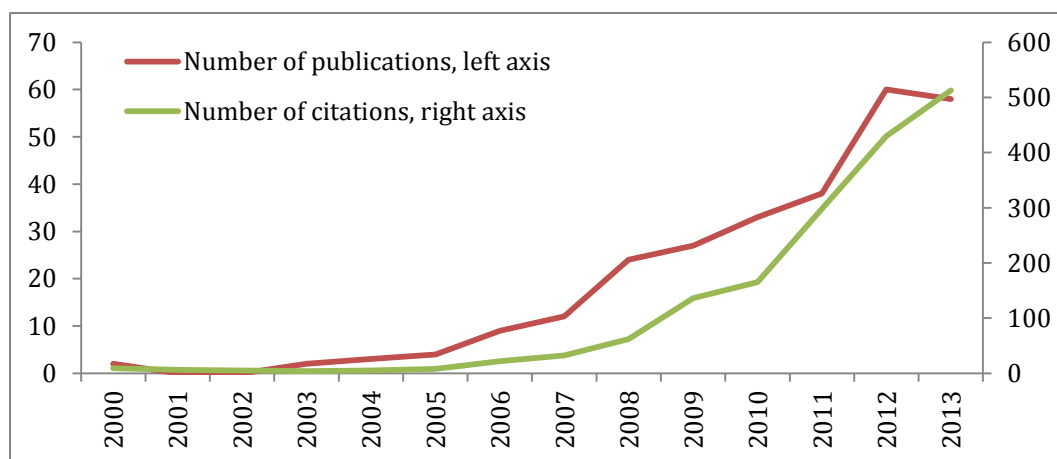
development that meets the needs of present generations without compromising the ability of future generations to meet their own needs.

From the economic perspective, sustainable development can be viewed in two ways. Firstly in terms of utility, where we demand that utility per capita should not fall over time. Secondly in terms of resources, where we demand that society's ability to generate well-being will be maintained. This means that resource stock should be kept constant (Hanley, Shogren & White, 2007). In the analysis that follows, the view of concern will be that renewable natural resources should be managed sustainably by

only utilising growth of the resource. Thus the resource stock should be kept constant for possible use by future generations.

In economic theory, the emphasis has been on increasing economic growth. This is built on the idea that by increasing our income we will at least not decrease our wellbeing. The bioeconomy term has been put forward as an extension of the sustainability term, to account for the importance of increasing economic growth (Staffas, Gustavsson & McCormick, 2013).

The term bioeconomy, or bio-based economy, has become a new buzzword. Searching in the Web of knowledge database shows that in the year 2000, publications and citations of articles with these words in their topic descriptions were almost non-existent. Since then, the number of publications referring to the bioeconomy has grown to approximately 60 per year and citations to over 500 per year. A similar result is found by searching in Scopus (Staffas, Gustavsson & McCormick, 2013).



**Figure 1: Publications and citations with topic “*bioeconomy*”, “*bio-economy*”, “*biobased economy*” or “*bio-based economy*” in the Web of Knowledge database (Thomson Reuters, 2013).**

A definition of the bioeconomy is still not clear, and different individuals and organisations define the bioeconomy in different ways. Different proposed definitions seem to have a common ground in terms of specifying the resources and products of the bioeconomy. Sectors and fields connected to the bioeconomy are also often mentioned (McCormick & Kautto, 2013). The terms of a bioeconomy or a bio-based economy are promoted as a technical fix for a development away from the use of fossil-based resources. A number of countries have published their own strategy or policy on the bioeconomy. These policies and strategies are generally concerned with increasing

the size of the bioeconomy and making each individual country a world leader in bioeconomic activity. They often neglect to consider the sustainable use of biomass, resource scarcity, the global perspective and how progress should be measured (Staffas, Gustavsson & McCormick, 2013).

The definition used for the bioeconomy or bio-based economy differs depending on which term is used, according to Staffas, Gustavsson & McCormick (2013). The term bioeconomy is generally used when referring to the part of an economy which uses biotechnology and life science. The bio-based economy is rather used to describe “an economy which is predominantly based on biomass for food, feed, energy and other purposes, rather than fossil-based resources” (Staffas, Gustavsson & McCormick, 2013).

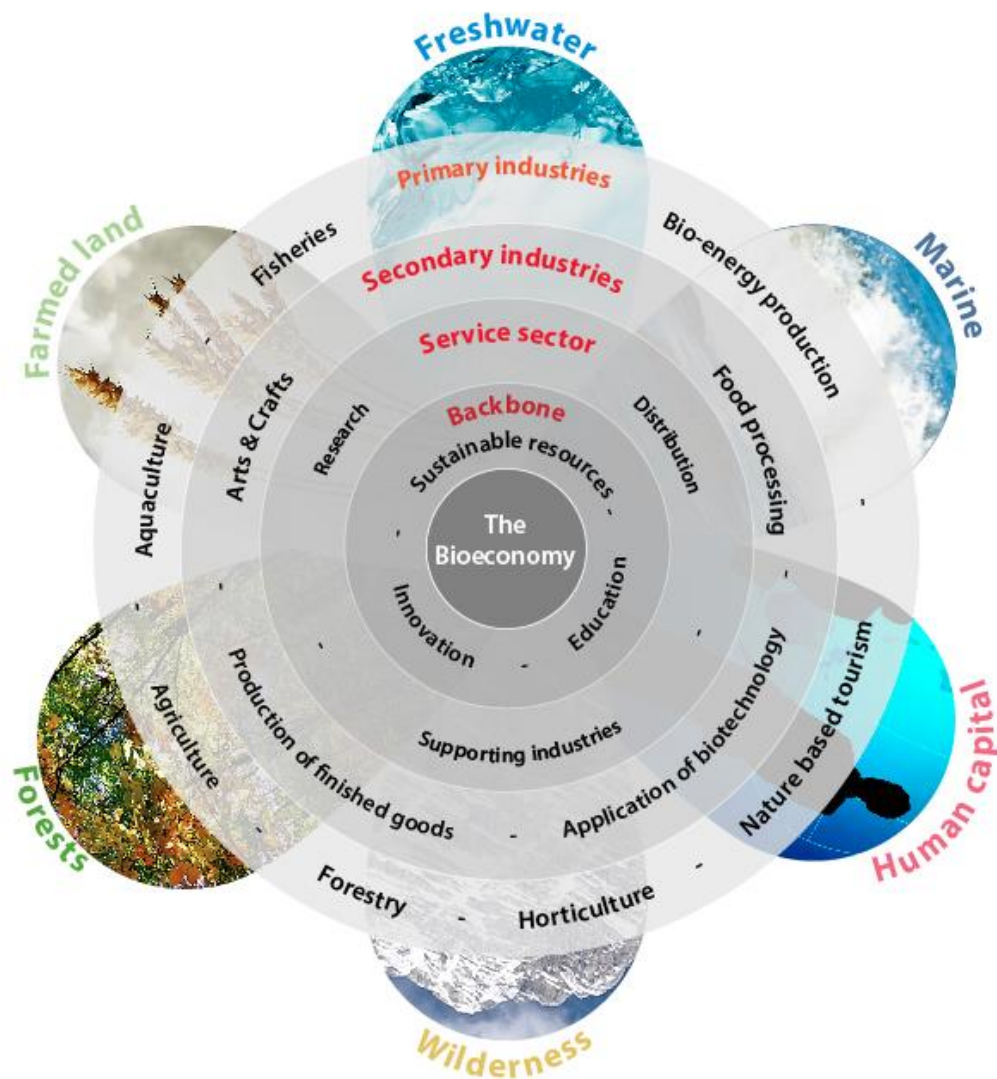


Figure 2: Proposed overview of the bioeconomy (Source: Matís and the Environment Agency of Iceland)



These two definitions suggest that the bioeconomy can be considered a part of a biobased economy. In what follows, the bioeconomy term will be used to indicate the part of an economy which is concerned with production and utilisation of biological resources. This vision of the bioeconomy reaches through all sectors of the economy and is best illustrated by figure 2.

The following analysis is built on the definition of the bioeconomy provided by the EC in their policy package. They define the bioeconomy as:

The bioeconomy ... encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy (European Commission, 2012).

This definition of the bioeconomy implies that the bioeconomy is concerned with both primary and secondary activities. However, other sectors may also be connected with the bioeconomy, that is they may include services to bioeconomic activities. Industries can not clearly be classified as either bioeconomic or non-bioeconomic, but we can consider them to have a bioeconomic component of various magnitudes.

## **2.2 Policies and strategies**

In 2009 the OECD published their book *"The Bioeconomy to 2030: Designing a policy agenda"* in which they evaluated the existing state of the bioeconomy and where it could be in 2015 and 2030. The OECD defines the bioeconomy to be part of a world "where biotechnology contributes to a significant share of economic output" (OECD, 2009). They acknowledge that a bioeconomy involves biotechnological knowledge, renewable biomass and integration across applications. Their evaluation of the existing bioeconomy specifies biotechnology applications in use within primary production, health and industry, in addition to covering the production of biofuels. Biotechnology is predicted to contribute to 2.7% of GDP in OECD countries by 2030. The drivers of development within the bioeconomy are considered to be a growing population and growing income per capita (OECD, 2009). The book gives a good overview of biotechnology availability and scenarios for development within biotechnology, but it is less concerned with the economic benefits and economic contribution of the bioeconomy. The measurement chosen for evaluation is biotechnology contribution to

GDP, suggesting that the goal of development within the bioeconomy is to maximise this contribution.

On the grounds of the Seventh Framework Programme for Research and Technological Development (FP7), the European Commission (EC) published their strategy for *“Innovating for Sustainable Growth: A Bioeconomy for Europe”* in 2012. The purpose of the strategy is to encourage “a more innovative, resource efficient and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes, while ensuring environmental protection.” The strategy defines the bioeconomy in a broader manner than the OECD definition, since it includes all extraction of, and production from, renewable biological resources, i.e. all value adding activity connected with biological resources. It is estimated that the European Union’s (EU’s) bioeconomy has an annual turnover of 2 trillion euros and accounts for over 22 million jobs. The EC further estimates that research funding under the strategy could generate an additional 130 thousand jobs and 45 billion euros in value added within the bioeconomy sectors, which should be accomplished with their action plan (European Commission, 2012).

Within the European Commission, the term Knowledge Based Bio-Economy (KBBE) has also been used. Clever Consult wrote a report for the EC on the KBBE in 2010, where a similar definition of bioeconomy is used to that in the EC strategy from 2012. This report was the basis for further work within the EC, and provided the estimates for annual turnover and employment within the bioeconomy in Europe (Clever Consult, 2010).

These documents show the increasing importance of a bioeconomy within Europe and the EU willingness to encourage development in a bioeconomic direction. The EU objective indicates that efficiency and competitiveness are of interest while considering environmental and sustainable constraints. This is not reflected in their chosen measurements; turnover and employment.

Within the Nordic countries, increasing emphasis is being put on the bioeconomy. In 2012, the Nordic Joint Committee for Agricultural and Food Research (NKJ) presented “The Nordic Bio-economy Initiative”, which is intended to promote development of the bioeconomy in the Nordic countries and to enhance Nordic cooperation in research in

this area (NKJ, 2013). The objective of this strategy is to support a progression from the current fossil-based to a bio-based economy, where renewable resources are used more extensively in a sustainable way without risking food security. The goal is to use current knowledge and gain new knowledge to help enhance value creation within the bioeconomy.

### 3 Bioeconomic activity

In this chapter, different methods to evaluate bioeconomic activity will be considered. The economic dimensions of the bioeconomy are considered. Other measurements of the bioeconomy may be of interest for other dimensions.

#### 3.1 Value added

All activity within the economy has a value. The value put on goods, services and resources differs between actors. Individuals within the economy put a value on things based on the utility that these things have to them. The value of bioeconomic activity is thus based on the utility that this activity provides for the society.

Let's consider the households of the economy and assume that households choose their consumption based on preferences. This suggests that for each pair of consumption bundles,  $x_1$  and  $x_2$ , a household will be able to state which one it prefers over the other. If assumed that preferences are complete, reflexive, transitive, continuous and strongly monotonic, then preferences can be represented as a continuous utility function of consumption goods,  $U(x)$  (Varian, 1992). The utility function is different for different households.

A production is an economic activity that transforms goods; that is a set of inputs  $x_{in}$  is transformed into a set of outputs  $x_{out}$ . It can be assumed that the production process has the aim of increasing the value of goods at hand. Value added of the production is the difference between the value of outputs and inputs. For a household, the value added of the production process can thus be defined

$$v = U(x_{out}) - U(x_{in}).$$

The value added is positive if the outputs have greater value than the inputs and negative if the inputs have greater value. Observe that a production process is beneficial for an actor if it's value added is positive.

If assumed that markets exist for all goods, markets are perfectly competitive and no market failures exist, then the first theorem of welfare economics states that a free market will reach a Pareto efficient allocation of goods (Varian, 1992). With competitive

markets, it can be assumed that prices represent utility to the society and then the value added of production can be approximated by

$$v = \mathbf{p} \cdot (\mathbf{x}_{out} - \mathbf{x}_{in})$$

where  $\mathbf{p}$  is a vector of prices.

In national accounts, the value added of economic activity is used to compute the gross domestic product (GDP). In the System of National Accounts, 2008 (2008 SNA), value added of production is considered as the value created by the process. It can be considered gross or net, where gross value added is “the value of output less the value of intermediate consumption”, and net value added is gross value added less the consumption of fixed capital. As a measure of value creation it is more correct to use net value added, but since consumption of fixed capital is difficult to estimate, gross value added is used (EC, IMF, OECD, UN & World Bank, 2009).

Valuation can be done on basic or producer’s prices. Using basic prices is the preferred method, but basic prices are the amount received by the producer from the purchaser, less taxes and plus subsidies. GDP is the sum of all value added at basic prices, plus all taxes and less all subsidies on products. Gross value added of a firm, industry or sector is considered a measure of contribution to GDP (EC, IMF, OECD, UN & World Bank, 2009).

National accounts are separated into three accounts; production, income and expenditure accounts. The production account uses the value added of industries,  $v_i$ , to compute the GDP as aggregated value added

$$\text{GDP} = \sum_i v_i = \sum_i \mathbf{p}_i \cdot (\mathbf{x}_{out,i} - \mathbf{x}_{in,i})$$

where  $i = 1, \dots, n$  and  $n$  is the number of industries. The income and expenditure accounts are built on the assumption that total value added of the economy, GDP, should be equal to total expenditure and total revenue of the economy (EC, IMF, OECD, UN & World Bank, 2009). Thus, by considering value added and contribution to GDP of industries, we are simultaneously considering the value creation of their production and their contribution to expenditure and revenue of the economy. For this reason GDP has commonly been used as a welfare measure, where GDP per capita measures the wellbeing of an average person in the economy (Mankiw, 1998).

GDP is not a perfect measure of wellbeing. It leaves out all activity that occurs outside of markets such as leisure and the environment. It also doesn't consider distribution of income within the economy (Mankiw, 1998). Value added is defined as the utility gain of production, which shows that measuring value added with market prices only gives the right measure of utility gain when prices are formed by perfectly competitive markets. That said, it can be concluded that GDP does not include all factors that contribute to wellbeing, and is dependent on free markets. However, it can also be assumed that an increase in GDP will not systematically decrease wellbeing.

### **3.2 Productivity**

In macroeconomic analysis, aggregated value added is considered a measure of aggregated output. It is assumed to be a function of the aggregated inputs capital and labour:

$$Y = F(K, L)$$

Here  $Y$  is gross value added,  $K$  is capital and  $L$  is labour. Productivity is a measurement which measures how efficiently these inputs are used in the production of output. Productivity is defined as the ratio between volume of outputs and inputs. The reasons for considering productivity are several; here three are of main concern. Firstly, to track technology changes, that is the known method of the economy to change resources into outputs. Secondly, economic efficiency is also commonly evaluated by productivity. It should be noted that economic efficiency does not imply maximum amount of output, but it implies profit maximisation of the firm. Thirdly, productivity of labour is directly connected to income per capita. Thus productivity is used to assess standards of living (Schreyer, 2001).

Indicators for productivity are as many as there are numbers of reasons to consider productivity. The goal of using a productivity measure should be known before choosing the indicator to use. When considering the contribution of an industry to productivity of the economy, the preferred measure of output is gross value added. The preferred measure of labour input is hours worked, and of capital input is productive capital stock. These measurements are not always available, and in these cases numbers of workers can be used to indicate labour input, and net or gross capital stock from national accounts can be used for capital input (Schreyer, 2001).

### 3.3 International trade

The theory of comparative advantage is built on the idea of an opportunity cost. Observations of comparative advantage and international trade are based on observations from Mankiw (1998). Opportunity cost is defined as whatever must be given up to obtain an item. The opportunity cost can be time, labour or other factors used in producing the item. Let's consider two actors,  $A$  and  $B$ , who produce two goods,  $i$  and  $ii$ . They can each produce a specific amount of each product or both products described by their production possibility set. If the opportunity cost of actor  $A$  for producing good  $i$  is less than the opportunity cost of actor  $B$  then actor  $A$  has a comparative advantage in producing good  $i$ .

When an actor has a comparative advantage in producing a good, trading will be beneficial. Note that although an actor can have absolute advantage in producing both goods, he can only have comparative advantage for one of the two. Trading will result in both actors having more of both goods. The theory of comparative advantage then states that international trade is beneficial for a country when it has a comparative advantage in producing some goods.

Allowing imports and exports of goods from a country will increase the economic wellbeing of the nation. This is built on the fact that with perfect markets the nation will export products that they have a comparative advantage in producing. This will give a higher price for the export good. The nation will import products that other countries have comparative advantage in producing resulting in a lower price of these goods. In total, international trade will increase the economic wellbeing of the nations involved. Export numbers give information on which industries an individual nation has specialised in.

### 3.4 Sustainability

The analysis of the bioeconomy is restricted to utilisation of biological resources. Problems arise when natural resources are considered since no property rights exist for these common goods. This market failure leads to overexploitation unless governed in a sustainable manner.

A sustainable utilisation of renewable natural resources is based on a given growth function for the resource. The growth function represents growth in the resource as a

function of current resource size. Let  $x$  stand for stock size of the resource and  $g(x)$  represent the growth function. In continuous time the growth function is determined by

$$\frac{dx}{dt} = \dot{x} = g(x(t), \mathbf{q}(t), t)$$

and in discrete time it is determined by

$$x_{t+1} - x_t = g(x_t, \mathbf{q}_t)$$

where  $\mathbf{q}$  is a vector of control variables which affect stock growth. Thus a growth function describes the development of the stock. The sustainable utilisation criterion specifies that the stock cannot be decreasing and thus the harvest cannot be greater than the growth. Equilibrium is reached where the stock size is constant, that is

$$\dot{x} = g(x) - h(e, x) = 0$$

where  $h(e, x)$  is the harvest represented as a function of effort,  $e$ , and stock size. A firm which utilises a renewable natural resource stock is expected to choose the effort level that maximises its profits. The firm's maximisation problem is

$$\begin{aligned} \max_e \pi &= ph(e, x) - we \\ \text{s.t. } g(x) &= h(e, x). \end{aligned}$$

Given function forms for the growth and harvest functions, the problem can be solved to give the optimal effort level for the firm. By using a continuous time or discrete time model rather than a static model, the optimal path can be observed in addition to the optimal state.

This simple model of utilisation of renewable natural resources shows that the problem has two dimensions. Firstly, there is an economic dimension representing the firm's profit maximisation. Secondly, there is the sustainable condition representing the need that harvest cannot exceed the stock growth. Taken together, it is a bioeconomic model representing the dynamics connected with natural resource utilisation.

This is not the only way to consider sustainability, as mentioned in Chapter 2.1. There are many suggested definitions for sustainable development. Another method for considering sustainability with an economic perspective is to consider welfare or utility gained by utilising the resource. The sustainability criterion is that welfare should not be decreasing. This can be represented by



$$\frac{dw}{dt} = w(\dot{x}, k) \geq 0$$

where  $w(x, k)$  is the welfare created with utilisation of natural resources  $x$  and man-made capital  $k$ . This is a weaker sustainability criterion, since if natural resources are partly or fully substitutable for man-made capital, then the resource stock can be decreasing without decreasing welfare. Here it is assumed that  $w_x > 0$  and  $w_k > 0$ . This sustainability criterion is also more difficult to observe. To create an indicator for this criterion we would not only have to estimate the resource stock, but also the welfare it creates. In what follows, we will consider the former sustainability criterion of non-decreasing stock size for natural resources.

## 4 Base industries

National accounts of economic activity measure the value added of all industries and represent the value added of an industry as its contribution to GDP. However, some industries seem to make a greater contribution than that which is represented in national accounts. Industries that seem disproportionately big can be considered to structure an economic base. Other industries seem to be dependent on this economic base. From observations on an economic base, a theory of base industries has been developed (Roy, Árnason, & Schrank, 2009).

The theory of base industries is best understood by considering a simple theoretical model. The discussion will follow the model introduced by Roy, Árnason and Schrank (2009). Let's assume that a natural resource is found in a region where no former economic activity took place. Utilisation of the resource will demand labour and thus a local population. The value added created by utilising the resource is represented with  $\theta$ . But the new population will demand consumption goods that can either be produced locally or imported. Value added of induced economic activity is represented with  $\varphi$ . Gross domestic product of the region is then:

$$y = \theta + \varphi$$

The economy described here has two sectors and four goods. The first good has value added  $\theta$  and is produced by utilising the natural resource. Assume that all of  $\theta$  is exported. The second good is the locally produced consumption good,  $x_1$ . The third good is the imported consumption good,  $x_2$ . The last good is assumed to be labour,  $l$ , but in this simple model we will exclude capital. All prices are presented in terms of price of the imported good, which thus has the unity price. Price of the domestic good is  $p$  and price of labour is  $w$ . Transportation costs of the imported good are represented with  $\varepsilon$ . The regional society will pursue maximisation of their utility with respect to their budget constraint; more precisely, they will try to solve the following problem:

$$\max_{x_1, x_2} U(x_1, x_2) \text{ subject to } y \geq px_1 + (1 + \varepsilon)x_2$$

Here  $U$  represents the utility function, which is assumed to be increasing and concave in both arguments. The solution will give an aggregated demand for consumption of local goods,  $D(y, p, \varepsilon) = px_1^d$ . Assume that the demand function is differentiable and that  $D_y, D_\varepsilon > 0$ ,  $D_p < 0$  and  $D_y < 1$ , where the last constraint means that changes in income will affect demand for domestic and foreign goods in the same direction. Total demand for domestic production is then:

$$y^d = \theta + D(y, p, \varepsilon)$$

Local producers of consumption goods are assumed to have the production function  $x_1 = Y(l)$  that is increasing and concave. They try to maximise their profits given the production function. In this way they solve the following maximisation problem:

$$\max_{x_1} pY(l) - wl = px_1 - C(x_1, w)$$

The firms cost function  $C(x_1, w) = w \cdot Y^{-1}(x_1)$  uses the inverse production function,  $Y^{-1}$ . The solution to the profit maximisation gives us the supply function of domestic production,  $S(p, w) \equiv p \cdot \psi(p/w) = p \cdot x_1$ , where  $S_p > 0$  and  $S_w < 0$ . Total supply of domestic production is then:

$$y^s = \theta + S(p, w)$$

Real wages within the region are an increasing function of real wages outside of the region, since labour is assumed to move freely. Therefore  $w/p = G(\bar{w})$  where  $\bar{w}$  are real wages outside of the region and  $G' > 0$ . Total supply of domestic production is then:

$$y^s = \theta + S(p, pG(\bar{w})) = \theta + F(p, \bar{w})$$

Where  $F_p > 0$  and  $F_{\bar{w}} < 0$ . At equilibrium, supply will equal demand and thus we get the following system of equations where  $y$  and  $p$  are endogenous variables and  $\theta$ ,  $\varepsilon$  and  $\bar{w}$  are exogenous variables:

$$y = \theta + D(y, p, \varepsilon)$$

$$y = \theta + F(p, \bar{w})$$

Differencing with respect to  $\theta$  results in:

$$\frac{\partial y}{\partial \theta} = 1 + D_y \frac{\partial y}{\partial \theta} + D_p \frac{\partial p}{\partial \theta}$$

$$\frac{\partial y}{\partial \theta} = 1 + F_p \frac{\partial p}{\partial \theta}$$

Together these equations give:

$$\frac{\partial y}{\partial \theta} = \frac{F_p - D_p}{F_p(1 - D_y) - D_p}$$

This equation is often referred to as the economic base multiplier (Frey, 1989) and reflects how GDP reacts to changes in production from a base industry. Following further the analysis of Roy, Árnason and Schrank (2009) the assumptions of the model give that:

$$\frac{\partial y}{\partial \theta} \in \left(1, \frac{1}{1 - D_y}\right)$$

This concludes that the base industry presented here has a greater contribution to GDP than its direct effects. The additional contribution of the base industry only happens when local consumption increases. It is also clear that since the base industry has an additional contribution to GDP, the other industry will have a reduced contribution to GDP. The upper limit of the multiplier is reached when  $D_p = 0$  or when  $F_p \rightarrow \infty$ . However, by assumption,  $D_p < 0$  and thus the base industry has more effect on GDP when supply of domestic products is more sensitive to prices (Roy, Árnason, & Schrank, 2009).

This model suggests that base industries can theoretically exist. In other words the GDP impact of an industry can be more than national accounts suggest. It also suggests that a base industry must have two characteristics. Firstly, the base economy must be exogenous with respect to the rest of the economy. This means that its existence should not depend on other industries within the economy. Secondly, its contribution to GDP should be greater than its direct effects and can be measured by the economic base multiplier. The model does not exclude the possibility of several base industries nor can we be sure that a base industry does exist in all economies (Roy, Árnason, & Schrank, 2009).

To draw the conclusion that an industry can be considered a base industry, the two characteristics must exist for the given industry. The former is a defining characteristic

of a base industry, while the latter can be argued for most industries. Thus, the former characteristic is of main interest to conclude on base industries (Ragnarsdóttir, 2012).

Roy, Árnason and Schrank (2009) suggest a statistical way to test whether an industry can be considered a base industry. They use the usual assumption from empirical macroeconomics, which is that there exists a stable relationship between production and primary factors for production. This is usually represented  $Y_t = A_t + \alpha L_t + \beta K_t$  where  $Y_t, L_t$  and  $K_t$  are the logarithms of output, labour and capital. Roy, Árnason and Schrank assume that if an industry acts as a base industry it must positively affect this relationship:

$$Y_t = A'_t + \phi F_t + \alpha L_t + \beta K_t$$

where  $F_t$  measures the base activity. The size of the base industry multiplier is reflected in the coefficient  $\phi$ . If this positive relationship is found it should be noted that this is neither a necessary nor sufficient criteria for a base industry (Roy, Árnason, & Schrank, 2009).

The multiplier effects of a base industry can be estimated statistically using methods described in detail by Roy, Árnason and Schrank (2009). The objective is to test the existence of a long-run relationship between GDP, primary factors of production and output of the base industry. Another method often used to analyse multiplier effects of an industry is the input-output analysis, where it is assumed that business between a base industry and other industries will increase the value added of these industries (Ragnarsdóttir, 2012).

It should be noted that not all industries can have greater contribution to GDP than national accounts suggest. This would result in a greater GDP. Therefore when some industries have a greater contribution, others must have a smaller contribution. Thus, when multiplier effects are accounted to an industry, the economic activity is simply moved between industries.

This review of base industries has introduced the idea of industries having a greater contribution to GDP than their direct contribution. This discussion has shown theoretically that base industries can exist. The characteristics of base industries have been described and concluding remarks have been made on the criteria needed for an industry to be considered a base industry.

## 5 Comparing different dimensions of the bioeconomy

Previous chapters have introduced what the bioeconomy is and also the dimensions of the bioeconomy according to theory. With data on these dimensions, a hypothesis can be made on whether these dimensions are correlated, or if the dimension of the bioeconomy can be reduced.

Principal component analysis (PCA) is perhaps the oldest and most frequently used multivariate statistical method. Its goals are to extract the most information from a data table and minimise the data needed to represent this information. These goals are reached by calculating new variables, the so-called principal components, which are linear combinations of the original variables. The principal components are created in a manner such that the first principal component has the largest possible variance. The principal components that follow are then created such that they are orthogonal on the previous components, and have the largest possible variance (Abdi & Williams, 2010).

A PCA analysis can be performed with most commonly used statistical packages. The R software for statistical computing has several different methods for performing a PCA analysis. The `prcomp` method of the `stats` package in R is the method that has been chosen here (R Core Team, 2013). The PCA analysis demands that variables used have the same scale, since it looks at aggregate variances across all variables. The `prcomp` method does offer the possibility of performing scaling on the data. A PCA analysis with scaling is a PCA analysis on the correlation matrix of the data, instead of on the covariance matrix (Abdi & Williams, 2010). Results from the PCA analysis are also dependent on the variables selected for the analysis. An equal number of variables should be chosen for each dimension in order not to over represent some dimensions.

Interpretation of a successful PCA involves looking at the variance explained by principal components in proportion to the total variance of the data set, and then interpreting how the principal components are linearly related to the original variables. Concluding that the dimension of the system can be reduced is possible when fewer principal components than original variables are needed to explain the variance of the data. Concluding which of the original variables provide partly the same information is

possible by looking at the loadings of the principal components. The loadings are the weights of the original variables in the principal component, and represent the correlation between a variable and a component (Abdi & Williams, 2010).

The different dimensions of the bioeconomy can each be measured over time, industries and countries. Thus, to conclude that a dimension reduction is possible, it is necessary to conclude that dimensions can be reduced over time, industries and countries.

After concluding if the dimensions of a system can be reduced, and which measurements are needed to draw conclusions on the system, analysis of clusters in the data can be performed. This can be done on the three levels already mentioned, clusters of years, industries or countries. Additionally, clusters of measurements or dimensions can be formed.

Hierarchical cluster analysis is a method that was developed in order to create mutually exclusive subsets of individuals with regard to specific characteristics (Ward Jr, 1963). This method can be used to create clusters of years, industries or countries with regard to the measurements or dimensions chosen after doing a PCA analysis. The stats package in R provides the method `hclust` that performs hierarchical clustering. A few different methods are available through `hclust` but here, the Ward's method will be used, where the objective is to minimise variance of the clusters and thus create compact, spherical clusters (R Core Team, 2013).

The PCA analysis and cluster techniques will be the methods used in this analysis to evaluate the theoretical dimensions of the bioeconomy and observe whether a cluster formation is found. This will be done for the dimensions of the bioeconomy at three levels; time, industries and countries.

## 6 Available data

### 6.1 Quantitative information

The quantitative dimension of the bioeconomy represents biological resources available. Data on biological resources in Iceland is available from several institutions based on different classes of resources. This data is generally presented per species.

According to Act no. 103, May 15 2002, on Livestock Ownership, the Icelandic Food and Veterinary Authority<sup>1</sup> is obliged to gather data twice a year on the state of the Icelandic livestock. Each autumn, all owners of livestock send a report to the Icelandic Food and Veterinary Authority with numbers of livestock by species. These reports are then double checked by inspectors in the spring. The data gathered is available online from the Icelandic Food and Veterinary Authority and Statistics Iceland<sup>2</sup>. The data used here is data on livestock, poultry and fur-bearing animal from inspectors, and data on crop production reported by farmers. The data gathered by the Icelandic Food and Veterinary Authority is available online as a time series from 1981 (Matvælastofnun, 2013). The Icelandic Food and Veterinary Authority, the Farmers Association of Iceland<sup>3</sup> and the Slaughterhouse Association of Iceland<sup>4</sup> track meat production from livestock, which is then published on the Statistics Iceland website as a time series from 1983 (Hagstofa Íslands, n.d.-d).

Figures on hunted wild animals are collected by The Environment Agency of Iceland<sup>5</sup>. All hunting licence holders are obliged to deliver a yearly hunting report to the agency. Aggregated hunting numbers are then available online by species on a yearly basis (Umhverfisstofnun, n.d.). In addition to this, The Nature Institute of East Iceland<sup>6</sup>

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<sup>1</sup> Matvælastofnun

<sup>2</sup> Hagstofa Íslands

<sup>3</sup> Bændasamtök Íslands

<sup>4</sup> Landssamtök Sláturleyfishafa

<sup>5</sup> Umhverfisstofnun

<sup>6</sup> Náttúrustofa Austurlands



publishes estimates on the reindeer hunting stock size for each year (Náttúrustofa Austurlands, 2007).

A new release, Arctic Biodiversity Assessment, from the Conservation of Arctic Flora and Fauna (CAFF) and the Arctic Council, gives a good overview of the biodiversity in the Arctic. This release provides tables of species found in each country, but not estimates of the stock sizes.

Figures on caught fresh water fish are gathered by the Institute of Freshwater Fisheries<sup>7</sup> and published online. The numbers are available by species and river (Veiðimálastofnun, n.d.). The Icelandic Aquaculture Association<sup>8</sup> provides numbers of slaughtered fish from Icelandic aquaculture (Landssamband fiskeldisstöðva, n.d.).

In addition to data on biological resources, data on land cover can give information on forests and other growth on the land. The CORINE<sup>9</sup> program is a European cooperation that is intended to gather data on land cover in European countries. The main purposes of the program are to gather comparable information on the environment for all European countries and use this information to follow development in Europe's land use (Árnason & Matthíasson, 2009). Land utilised for agriculture is further accounted for in data from the farm structure survey conducted by Statistics Iceland in 2011 (Hagstofa Íslands, n.d.-d).

The Directorate of Fisheries<sup>10</sup> holds the executive power on fisheries. They collect data on catch by weight reports from fishing vessels (Fiskistofa, n.d.). This data is aggregated and presented in an accessible manner by Statistics Iceland (Hagstofa Íslands, 2012). The state of the fish stocks is estimated by the Marine Research Institute<sup>11</sup> (MRI) and reported annually. The reports give numerical indications of stock size for several species and have the main purpose of advising on the sustainable use of

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<sup>7</sup> Veiðimálastofnun

<sup>8</sup> Landssamband fiskeldisstöðva

<sup>9</sup> CORINE stands for *Coordination of Information on the Environment*

<sup>10</sup> Fiskistofa

<sup>11</sup> Hafrannsóknarstofnun

the fish stocks (Hafrannsóknarstofnun, n.d.). Currently no data is available on other biological resources of the sea.

## **6.2 Economic activity**

All major data on economic activity in Iceland is gathered and distributed by the statistics office in Iceland, Statistics Iceland.

National accounts in Iceland follow a European version (ESA 95) of the System of National Accounts (SNA 1993) provided by the United Nations. This makes Icelandic national accounts comparable to most OECD countries. The Icelandic national accounts are completed using both the production approach and the expenditure approach, but the income approach is not applicable. Using data from the production approach gives us the opportunity to look at industries output, as part of gross domestic product or gross value added, and to create productivity measurements by industries, using capital stock and labour estimates (Hagstofa Íslands, 2011).

Industry categorising used by Statistics Iceland is built on the European classification NACE Rev. 2, which was provided by the European Commission in 2008. The Icelandic classification is called ÍSAT2008, and has been adapted to local conditions in Iceland by a working committee at Statistics Iceland. Icelandic firms are classified according to ÍSAT2008 based on their main activity, that is their activity that has the most value added (Hagstofa Íslands, 2009).

Statistics Iceland has performed labour market surveys from 1991. From 1991 to 2002 two surveys were conducted each year, but from 2003 the surveys have been conducted throughout the year and the results published quarterly. The survey is built on international standards and its data has been sent in standardised form to Eurostat<sup>12</sup> from 2005. Data from the survey provide us with estimates on the labour market, employment, unemployment, wages and working hours. Some of these numbers are available per industry (Hagstofa Íslands, n.d.-b; Harðarson & Tryggvadóttir, 2003).

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<sup>12</sup> Statistical Office of the European Union

In Iceland, tracking of imports and exports is done by the Directorate of Customs<sup>13</sup>. Data on external trade are published by Statistics Iceland and can be analysed by various international classification standards. Information on exports is additionally available through a special classification developed by Statistics Iceland, which gives a better opportunity to analyse exports on bases of resources. Numbers for external trade both include weight and value in ISK. The general rule is to consider FOB<sup>14</sup> value for exports and CIF<sup>15</sup> values for imports (Hagstofa Íslands, n.d.-a).

The Directorate of Internal Revenue<sup>16</sup> supervises tax assessment in Iceland. Tax on companies is based on their turnover and thus numbers on enterprise turnover, by industry, are available on the Statistics Iceland website (Hagstofa Íslands, n.d.-c).

### **6.3 Economic activity in other countries**

Icelandic data on economic activity are produced by international standards and can thus often be compared to data from other countries. Many of the standards are developed for Europe. Eurostat has accessible data for many European countries on their website. These data sets can be used to compare Iceland to other European countries.

Numbers on economic activity in the Nordic countries is available from the Nordic Council of Ministers. Each year the council publishes the Nordic Statistical Yearbook. It shows comparable statistical data on the Nordic countries. The data are gathered from statistical offices in each country and presented in a comparable way. Data on the Faroe Islands and Greenland are represented separately. A time series for this data is available online (Nordic Council of Ministers, n.d.).

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<sup>13</sup> Tollstjóri

<sup>14</sup> Free On Board

<sup>15</sup> Cost, Insurance, Freight

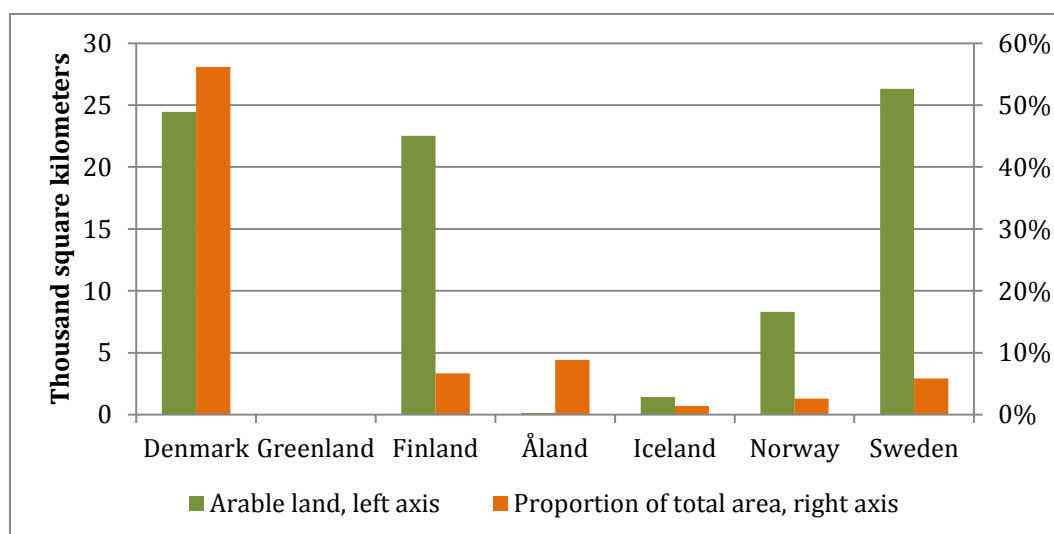
<sup>16</sup> Ríkisskattsjóri

## 7 Results

### 7.1 Quantities of biological resources

This chapter has the objective of giving a point estimate of the biological resources available in Iceland in the year 2010.

Agriculture in Iceland is divided into livestock breeding and crop production. In 2010, the value of crop products was 27.4% of the total agricultural output value while the value of livestock products was 67.3% of the total agricultural output value. Land utilised for crop production covered only 75 km<sup>2</sup>, while 15.834 km<sup>2</sup> were utilised for grazing and hay production. Total arable land in Iceland is significantly less than that found in the other Nordic countries, with the exception of Greenland, which has even less arable land than Iceland. The proportion of arable land in Norway seems to be not much higher than that in Iceland. Norway is also partly within the Arctic area.

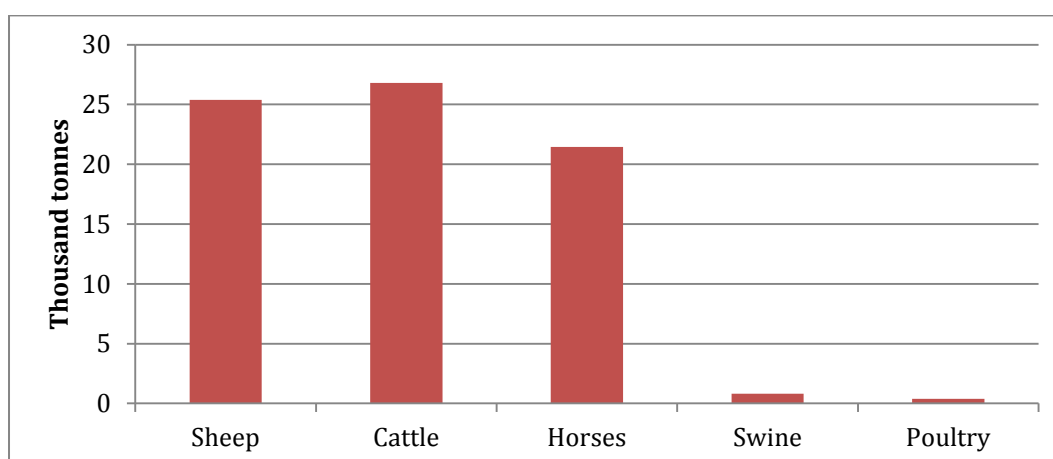


**Figure 3: Total arable land and its proportion of total area in the Nordic countries for the year 2010**  
(Source: Nordic Council of Ministers)

Estimates of numbers of animals on Icelandic farms in 2010 are presented in table 12 in the appendix. They suggest that Icelandic livestock consisted of 636 thousand animals, of which there were 480 thousand sheep, 77 thousand horses, 74 thousand cattle, 4 thousand pigs and under one thousand goats. That year on Icelandic farms, there were 320 thousand birds of the species *Gallus domesticus*, of these around 100

thousand were chicks. Numbers of chicks represent only the chicks at a specific time rather than on a yearly basis. A total number of 4,357,819 poultry were slaughtered in Iceland in 2010. Other poultry bred in Iceland are turkeys, ducks and geese; together they were estimated to be fewer than 5 thousand in number. Fur-bearing animals on Icelandic farms are primarily mink, which numbered 37 thousand in 2010.

The biomass of adult animals was estimated and is presented in figure 4. The number of animals was multiplied by the average weight of the species which was obtained from The Reykjavík Domestic Animal Zoo and Family Park<sup>17</sup>. The adult livestock consists mainly of sheep, cattle and horses. It should, however, be noted that horses are rarely kept for meat production and their biomass can thus not be interpreted in the same way as for sheep and cattle. These estimates do not indicate production but rather are indicative of production possibilities.



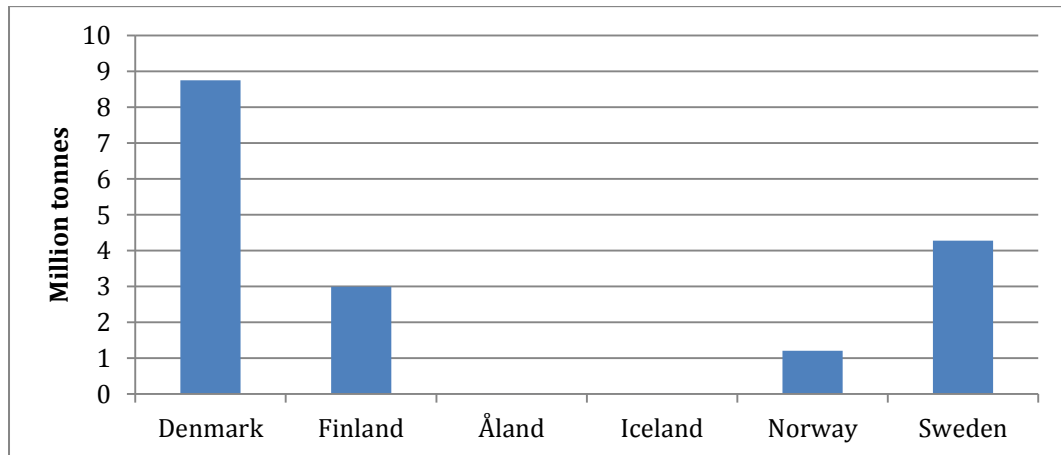
**Figure 4: Biomass of Icelandic livestock in 2010 (Source: Icelandic Food and Veterinary Authority)**

The cultivation of plants for food production and horticulture is also evident in Iceland, but only to a small degree, as noted above. Crop production, other than hay, in the year 2010 was 13,175 tonnes of cereals and 18,484 tonnes of vegetables. Production of potatoes forms the largest part of vegetable production, and 12,460 tonnes of potatoes were produced in 2010. Hay production was not included since it is considered part of livestock breeding. In 2010, total hay production was over 2 million cubic metres.

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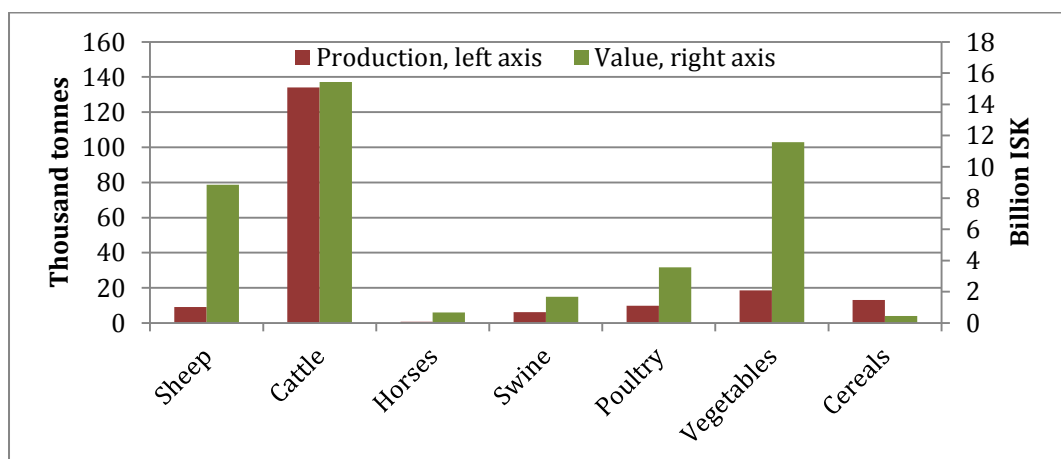
<sup>17</sup> Húsdýra- og fjölskyldugarðurinn.

Comparing crop yield of the Nordic countries again demonstrates how relatively small crop production is in Iceland. Denmark, which is less than half the size of Iceland, has a crop yield of over 8 million tonnes while Iceland produces only a few thousand tonnes. This is, of course, connected to the fact that only a small part of Iceland is arable land.



**Figure 5: Total crop yield in the Nordic countries in 2010 (Source: Nordic Council of Ministers)**

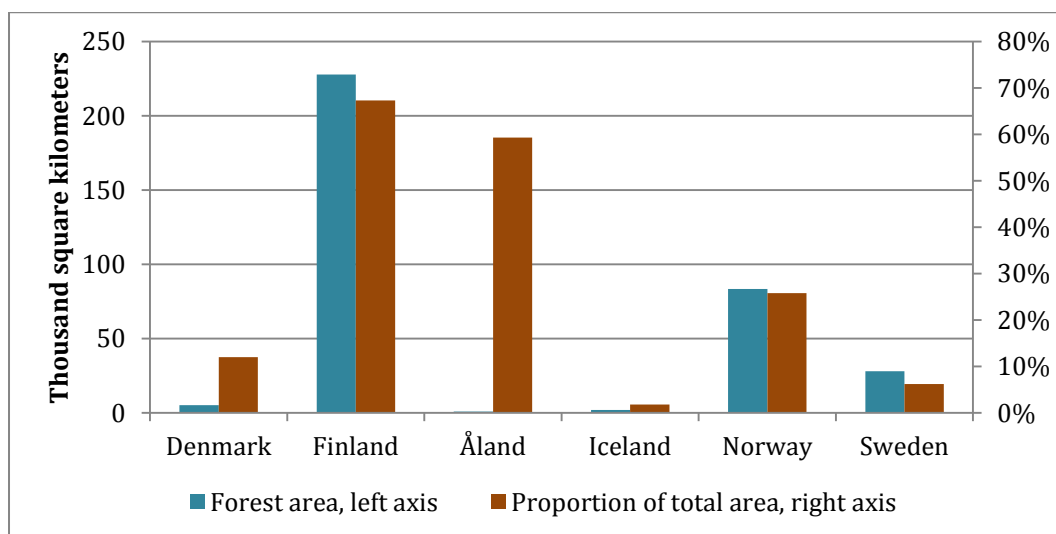
Total food production from livestock and crops is compared in figure 6. The high amount of cattle output in tonnes is due to milk production, which is included here. Cattle and vegetables create the largest yield, both measured in weight and value. Cereals are the third biggest source of production in weight, but this is not reflected in its value. Sheep production has the third highest output value since it is a high value product.



**Figure 6: Agricultural food production in tonnes and value of production in ISK in 2010 (Source: Statistics Iceland)**

Forests cover only a small part of Iceland. The total area covered by forests in Iceland is 1,568.6 km<sup>2</sup> of which natural birch forests cover 1,155 km<sup>2</sup> and cultivated forests cover only 413.5 km<sup>2</sup> (Traustason & Snorrason, 2008). This is less than 1% of the total area of Iceland. Here, natural birch bushes of under 2 m height have been included, and they cover 918.5 km<sup>2</sup>.

Land covered by forests differs between the Nordic countries. Figure 7 shows both area of land covered by forests and its corresponding proportion of total land area. The figures are not for a specific year, but the most up to date numbers available are used for each country. Finland, including Åland Islands, has over 50% of its area covered by forests. The only other Nordic country to come close to this proportion is Norway, with around 25% of Norwegian land covered by forests. Closest to Iceland is Sweden with 6% of its land covered by forests. It should, however, be noted that numbers for Greenland and the Faroe Islands were not available. Greenland and the Faroe Islands are likely to have a similarly low percentage of land covered by forests as does Iceland, or even lower.



**Figure 7: Area of land covered by forests and its proportion of total land area for the Nordic countries**  
(Source: Nordic Council of Ministers)

Uncultivated areas in Iceland, consisting of wilderness land, do include some biomass. A part of this area is grown areas, mainly moors and heathland, but the main contribution is from wild animals living there. These animals are hunted and most often used for personal use. Hunting of birds is the most common activity, and in 2010 a total number of 283,487 birds were hunted. Ptarmigan is the most hunted, and the second

most hunted are goose species. Further breakdown of hunting numbers are shown in table 7 in the appendix.

A few other animal species are hunted wild in Iceland. Reindeers were imported to Iceland and have since lived wild in the east of Iceland. In 2010, there were 1,229 reindeers hunted in Iceland. That year, the hunting stock was estimated to be 6,400 reindeers and it was suggested that the hunting allowance would be 1,272 animals (Þórisson & Þórarinsdóttir, 2011). American minks and arctic foxes can also be found wild in the Icelandic countryside. The arctic fox is the only native land mammal in Icelandic nature. In 2010, there were 5,327 mink and 7,808 foxes hunted in Iceland.

According to CORINE land cover classification, water covers 2.3% of Iceland's total area, amounting to 2,386 km<sup>2</sup>. The most used biological resources from these areas are caught wild fish. The three main species of fresh water fish are salmon, sea trout and river trout. Fishing in fresh water is mainly recreational rather than commercial, and therefore the value of the fish mainly comes through sold fishing licenses. Caught fish is principally for personal consumption. In 2010, a little over 140 thousand fresh water fish were caught in Iceland, nearly half of which were salmon. A further breakdown is provided in table 8 in the appendix.

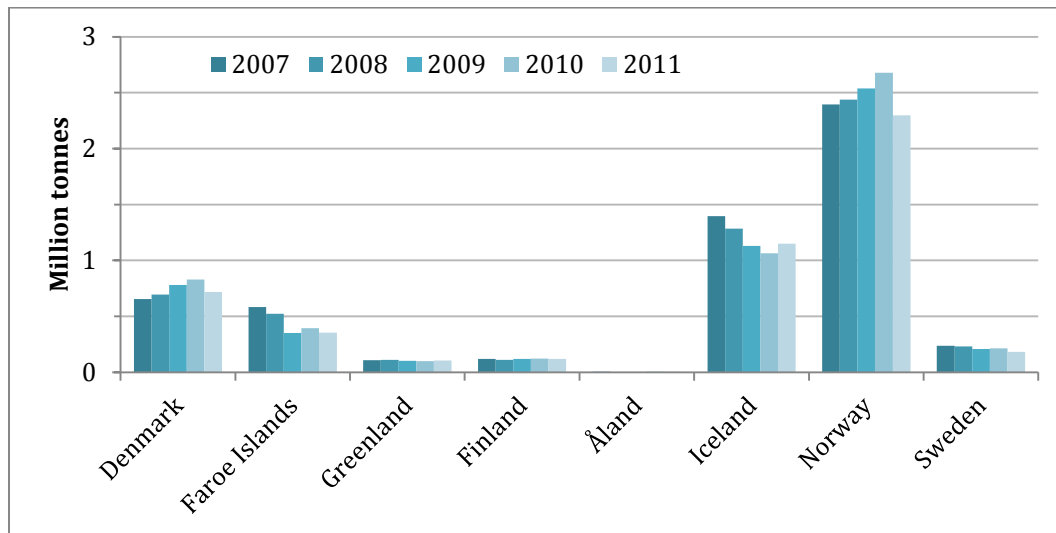
The resources of the sea are not as accessible as land resources. This means that stock estimates of sea fish are expensive to conduct. Stock estimates are only conducted for the most valuable species in Iceland. Where available, stock estimates for Icelandic fish species are presented in table 10 in the appendix.

Since stock estimates are not always available, we will use catch weight as an indicator of the resource quantity. The total catch of the Icelandic fleet in the year 2010 totalled 1.1 million tonnes, of which the most caught species were herring, cod, capelin and haddock, in descending order. The catch can be divided into demersal fish, flatfish, pelagic fish and shellfish. In 2010, over half of the catch was pelagic fish and around 40% was demersal fish. Further breakdown of the Icelandic catch in 2010 is presented in table 9 in the appendix.

The Nordic countries do not all have an accessibility to marine resources equivalent to Iceland. This is quite evident when the total catch of the Nordic countries is compared. Norway catches almost twice as much as Iceland. Denmark and the Faroe



Islands also have significant marine catches. Greenland has a surprisingly low total catch even though their accessibility to the sea is similar to that of Iceland's. Their difficulty is that when catch has been landed, the accessibility to markets is not as good as in Iceland.



**Figure 8: Total marine catch of the Nordic countries in the period 2007-2011**  
(Source: Nordic Council of Ministers)

Commercial whaling of fin whales and common minke whales is permitted in Iceland. In the year 2010, the Icelandic whaling fleet caught 148 fin whales and 60 minke whales. Since 2010, whaling of fin whales has stopped and whaling of minke whales has decreased to 52 in 2012. Fishing of seals also occurs. In 2010, there were 451 seals fished, but of these, 259 were bycatch.

The flora of the sea has not yet been utilised extensively but is receiving increased attention, and several research projects on its utilisation are being conducted. Therefore, it can be expected that utilisation will increase in the coming years, and a clearer indication of the resources available and their value will become available.

Aquaculture has existed for some time in Iceland. The most common farmed species are salmon, trout and cod. In 2010, the most slaughtered species was Arctic char followed by Atlantic salmon and cod. The total weight of slaughtered fish from aquaculture in Iceland in 2010 was only approximately 5 thousand tonnes, compared to over 1 million tonnes in Norway and around 40 thousand both in Denmark and the Faroe Islands. Although aquaculture may be important for the development of food

production in Iceland, this comparison shows that Icelandic aquaculture is still relatively small on the global market.



**Figure 9: Weight of slaughtered fish from aquaculture in the Nordic countries in the period 2007-2011**  
(Source: Nordic Council of Ministers)

## 7.2 Sustainability

The strong sustainability rules concerning the depletion of natural resources say that the harvest should equal the growth of the resource given that the resource is at equilibrium. In the case of the bioeconomy, what is of interest is that wild biological resources should be managed in a sustainable manner. These resources are vegetation on land, wild animals and birds, and living resources of the sea.

Land degradation in Iceland has been a big problem. Numbers detailing land cover suggest that large parts of Iceland are barren and that there are hardly any forests in the country. When man settled in Iceland, the land was fully vegetated. Nature has had its effect on land depletion but grazing and forest utilisation have also not been sustainable. There has been increased emphasis by the government on working against land degradation (Arnalds & Barkarson, 2003).

The reindeer stock in Iceland is estimated each year by the Nature Institute of East Iceland. They suggest a hunting allowance each year based on the stock size. The main goal is to keep the utilisation of reindeers sustainable and to make sure that the stock is not too big for the land to bear. The reindeer stock has been in good shape over recent years suggesting a successful sustainable utilisation process (Þórisson & Þórarinsdóttir, 2013).

All wild birds and mammals in Iceland are supposed to be managed in a sustainable manner, according to Act no. 64, May 19 1994, on Protection, Conservation and Hunting of Wild Birds and Wild Mammals. The Nature Institute of Iceland has the obligation of observing stocks of wild birds and wild mammals and makes suggestions on their protection when needed.

An Individual Transferable Quota system was introduced in Iceland in 1984. In the 1980s, a significant decline in the Icelandic fish stocks was discovered. This led the government to introduce a catch rule in 1995. The catch rule ordered that the total allowable catch of the Icelandic fleet would be set following recommendations by the MRI (Agnarsson et. al., 2007). The MRI bases their recommendations on the objective of having a sustainable depletion of the resource. From the winter of 1995-96, the total catch of the Icelandic fleet has been in synchrony with the MRI recommendation. Thus, it can be stated that according to the best knowledge available, the fish stocks have been depleted in a sustainable manner since 1995 (Haraldsson & Carey, 2011).

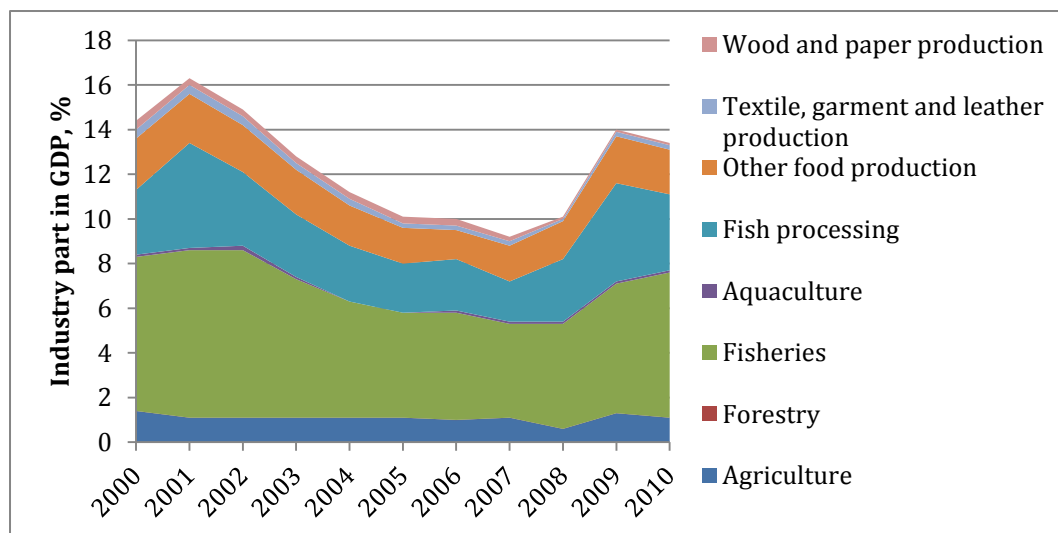
### **7.3 Economic performance**

The Icelandic economy is a resource-based economy where natural resources play a large role. In 2010, the resource sectors of the economy accounted for over 80% of total exports, which was over 697 billion ISK, and for 24% of gross domestic product (GDP). Of the resource based exports, one quarter was from the fishing industry. Other major parts of the resource sector are tourism and metal manufacturing (McKinsey & Company, 2012). The bioeconomy includes the fishing industry but not metal manufacturing and only partly tourism. This demonstrates how big the bioeconomy is in Iceland and especially how big the fishing industry is.

Primary production within the bioeconomy consists principally of the fishing industry, which contributed to 9.9% of Iceland's GDP in 2010. The fishing industry includes off shore fishing and fish processing, and their contributions to GDP are 6.5% and 3.4% respectively. Other primary production comes from agriculture and other food processing, excluding fish processing, fish farming and forestry. Agriculture in total, including both crop production and livestock breeding, constitutes 1.1% of GDP. Food production, excluding fish processing, constitutes additionally 2% of GDP. Fish farming constitutes 0.1% of GDP but forestry does not have a measurable effect.

Secondary production within the bioeconomy can partly be tracked by industries. For example, textile, garment and leather production and wood and paper production constitute 0.2% and 0.1% of GDP respectively. Other industries may have connections to the bioeconomy but their contribution to the bioeconomy can only be evaluated using multiplier effects, which we will discuss later.

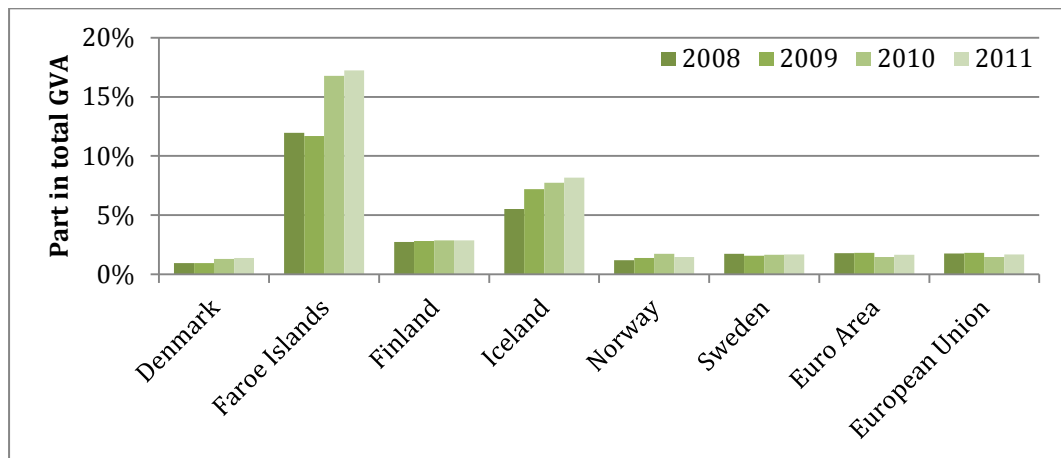
In total these bioeconomic industries accounted for over 13% of GDP for the year 2010. This is an underestimate of the total contribution of the bioeconomy to Icelandic GDP. Development of the bioeconomy's contribution to GDP shows how it reached a trough level around 2007 but has since increased. This development is connected to the economic crash in 2008. Gross value added of all industries in Iceland peaked in 2008 but has since been declining, while gross value added of bioeconomic primary production reached its minimum in 2007 and has since been increasing. This can be seen when looking at the gross value added on constant 2010 prices.



**Figure 10: The bioeconomy industries in Iceland and their contribution to GDP**  
(Source: Statistics Iceland)

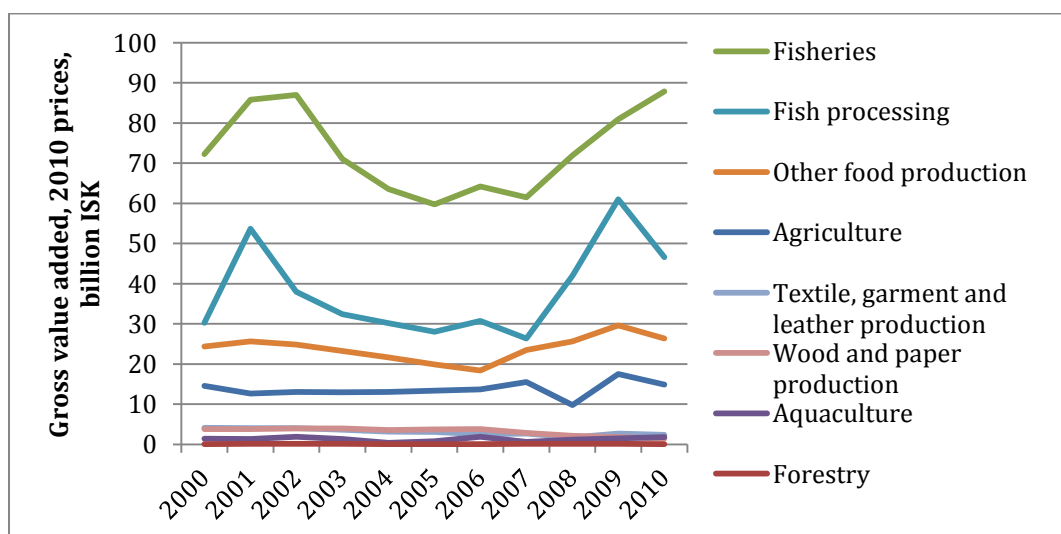
Gross value added (GVA) of an industry is the measure used to calculate contribution to GDP. Primary production within the bioeconomies of the Nordic countries can be compared by looking at their part in total GVA. The comparison shows that in other Nordic countries, the bioeconomic primary production is significantly less than in Iceland and the Faroe Islands for the years 2008-2011. The same applies to other European countries in the Euro area or in the European Union. The Faroe Islands have a

significantly greater part of total GVA contributed by primary production than Iceland, over 17% in 2011.



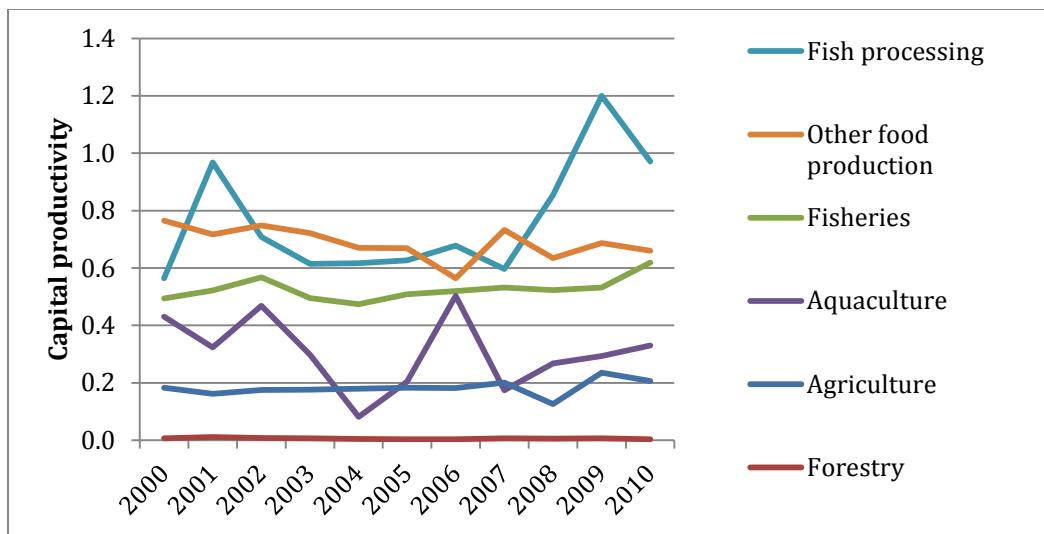
**Figure 11: Agriculture, forestry and fishing part in total GVA for the Nordic countries and Europe in the period 2008-2011 (Source: Nordic Council of Ministers)**

Figure 12 shows the gross value added of bioeconomic industries in Iceland on constant 2010 prices. Value creation is greatest in the fishing industry, followed by other forms of food production (excluding fish processing and agriculture). Other industries considered have a significantly lower value creation. We see an obvious trend within the fishing industry where gross value added dramatically reduced between 2003 and 2008, but has increased since the crisis. This can be considered partly due to fluctuations in the Icelandic Krona, since the revenue of the fishing industry is created primarily from exports.



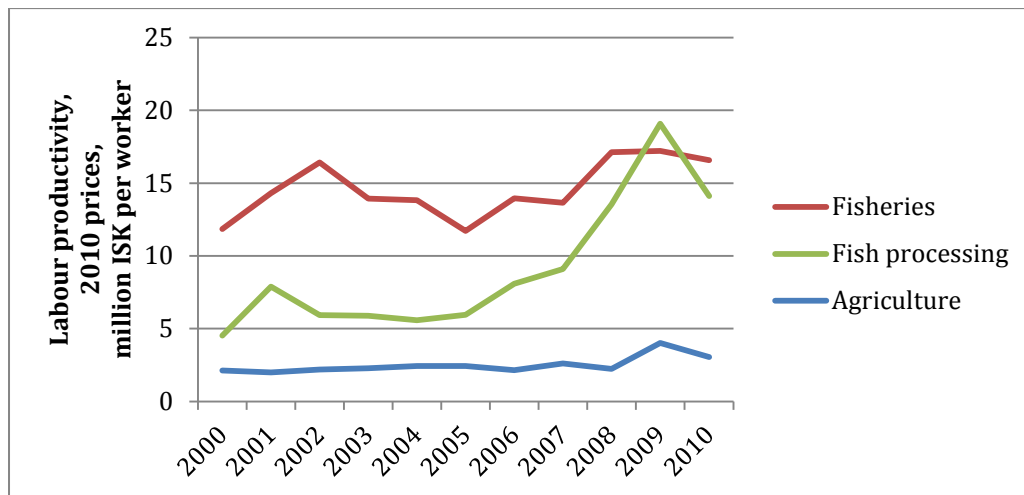
**Figure 12: Gross value added, in 2010 prices, of bioeconomic industries in Iceland (Source: Statistics Iceland)**

Capital productivity of an industry is total gross value added of that industry divided by its capital stock. Figure 13 illustrates capital productivity of bioeconomic industries, where more advanced forms of production have been omitted on the grounds of their small size. The capital productivity does not give the same ordering of industries as seen in figure 12. Thus, this indicator can provide a different dimension to estimates of the economic performance of individual industries. The fluctuations in the data are more pronounced, but it seems evident that more advanced production has higher capital productivity than primary production.

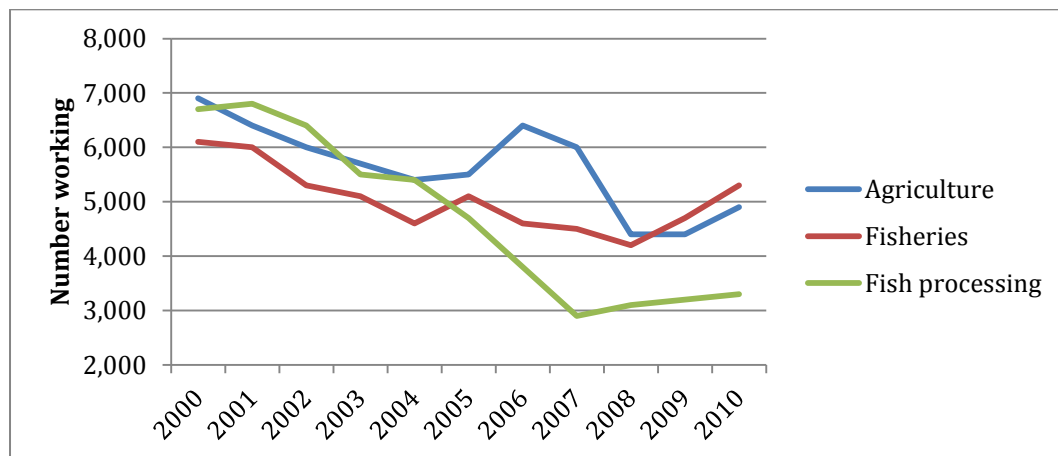


**Figure 13: Capital productivity for bioeconomic industries (Source: Statistics Iceland)**

Labour productivity of an industry is total gross value added of that industry divided by labour input. The ideal measure of labour input is hours worked, but data on numbers of workers can be used instead. Labour productivity for the three biggest bioeconomic industries is illustrated on figure 14 where numbers of workers has been used. Over the period there was not much variation in labour productivity. There is a positive trend in labour productivity in fish processing, commencing in 2005. It is also clear that fisheries and fish processing have higher labour productivity than agriculture. Looking at the trend in number of persons in the workforce, in figure 15, we see that numbers of workers have been declining over the last decade, with a slight increase after the crisis. This contributes to the trend of increasing labour productivity and the slight decrease in 2010.



**Figure 14: Labour productivity for the three main bioeconomic industries (Source: Statistics Iceland)**

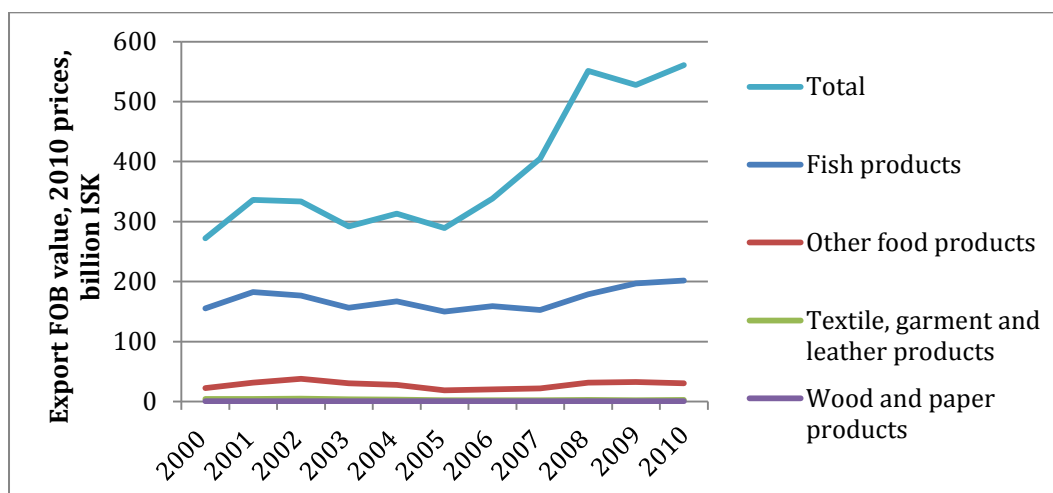


**Figure 15: Number of people working in the three main bioeconomic industries (Source: Statistics Iceland)**

When considering the workforce, it is also interesting to consider its composition. For example, over the last decade it appears that around 85% of jobs within the bioeconomy have been outside the capital. In addition, the bioeconomy employs twice as much of the total workforce in the countryside than it does in the economy as a whole. This indicates that the bioeconomy supports regional development strategies.

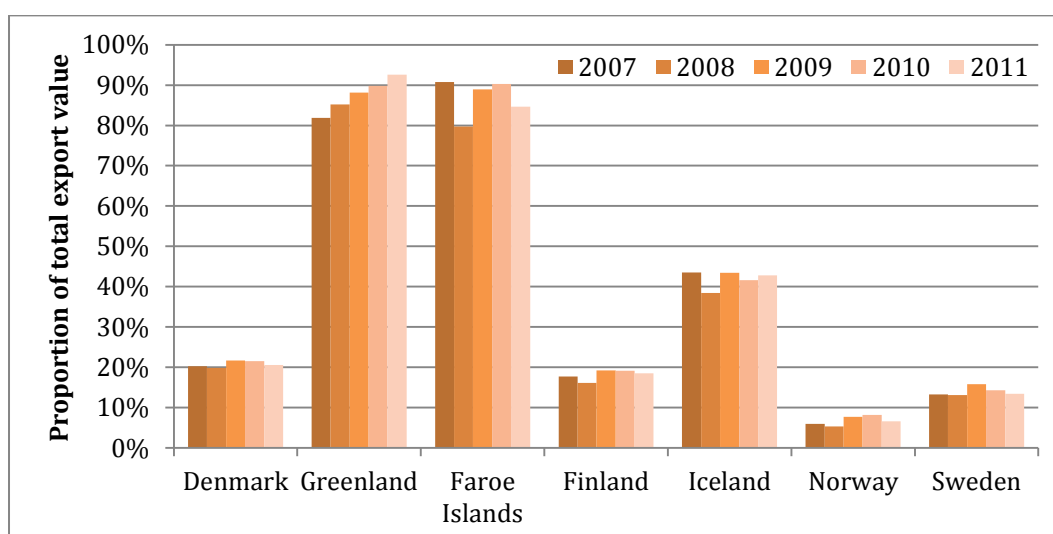
Exports can also be an indicator of economic performance. Exports cannot be tracked by industries as we have classified them up to this point, but we can track exports by product origin. Figure 16 shows that fish products have been a large part of exports over the last decade. On constant 2010 prices, it is evident that the value of fish exports has been relatively constant but an increase in total export value can be seen from 2005. This can be explained by increased exports by the aluminium industry. It is

also evident that other food products have some export value, but other products of biological origin do not seem to have significant export values.



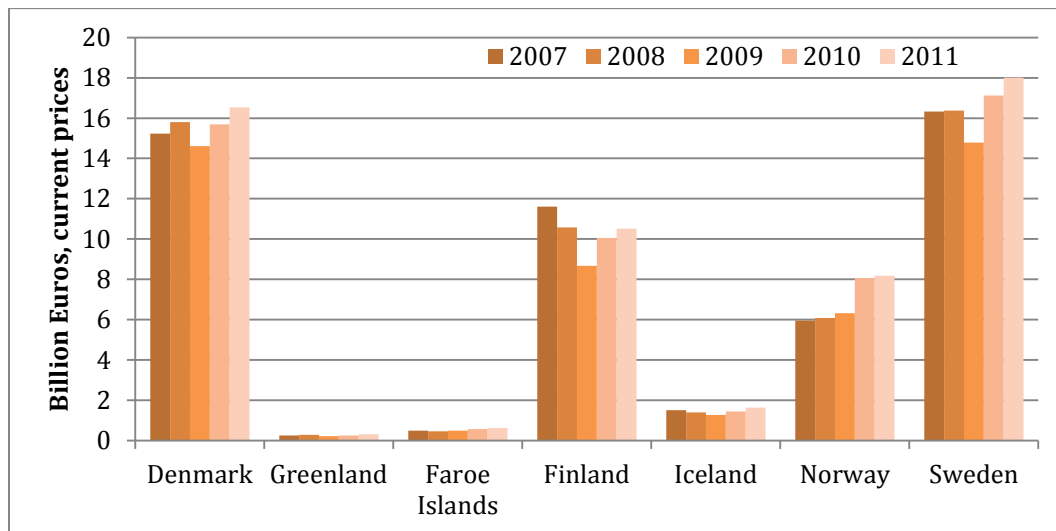
**Figure 16: Export FOB value of products of biological origin in comparison with total exports**  
(Source: Statistics Iceland)

Looking at exports of products of biological origin in the Nordic countries, it can be seen that Iceland is the third most dependent country on biological resources. Greenland and the Faroe Islands are the only countries with a higher proportion of export value from products of biological origin. When looking at export values for this group of products, it is clear that in Iceland, Greenland and the Faroe Islands, these products have much less export value. Exports from these three countries are homogenous and of less value than seen in the other Nordic countries.



**Figure 17: Products of biological origin proportion of total export value for the Nordic countries in the period 2007-2011** (Source: Nordic Council of Ministers)





**Figure 18: Export value of products of biological origin for the Nordic countries in the period 2007-2011 (Source: Nordic Council of Ministers)**

#### **7.4 Base industries and multiplier effects**

The theory of base industries is of interest when considering the bioeconomy since it can clarify whether the contribution of the bioeconomy is greater than that suggested in chapter 7.3. Here, former analysis of bioeconomic industries will be considered to see whether the industries that make up the bioeconomy can be considered base industries. Following this, these results will be taken together to conclude whether the bioeconomy as a whole can be considered a base industry.

The fishing industry is a base industry in Iceland, although not necessarily the only one (Árnason & Agnarsson, 2005). Analysis by Árnason and Agnarsson (2005) suggests that the fishing industry's contribution to GDP is much greater than suggested by national accounts. Extensive research exists on many aspects of the fishing industry, because of its importance to the Icelandic economy. This includes research on value creation and the contribution of the fishing industry to the economy. In order to measure the total contribution of the fishing industry, theories of business clusters, put forward by Michael E. Porter, have been used to define the ocean cluster and measure its effect on the economy. The result suggests that the ocean cluster contributed to 26% of Icelandic GDP in 2010 and employed approximately 25 thousand people (Árnason & Sigfússon, 2012). The analysis on the ocean cluster takes into account the effect of the fishing industry on industries from all sectors of the economy. Also, it should be noted

that fishing, aquaculture and fish processing are all considered part of the ocean cluster's direct contribution to the economy.

Agriculture is a foundation in many economies, especially less developed economies. Agriculture accounts for only a small part of the Icelandic economy. According to national accounts from 2005, agriculture only contributes to around 1.5% of GDP and that employment is 2.5% of total labour. However, by taking into account indirect employment, around 10,000 jobs are connected with agriculture, which is 5.6% of total labour in 2005 (Jóhannesson & Haraldsson, 2009). The multiplier effects of employment within the agriculture sector suggest that employment is 124% more than national accounts suggest. If this estimate is used to estimate the multiplier effect of contribution to GDP in 2010, we see that agriculture constitutes 2.5% of GDP, whereas national accounts suggest 1.1%.

But, can agriculture in Iceland be considered a base industry? It proves difficult to state that agriculture in Iceland is exogenous to the rest of the economy. This is especially true when taking into account the fact that subsidies to production in agriculture were 0.9% of GDP in 2010, and have been similar in previous years (Source: Statistics Iceland). Conditions for agriculture in Iceland are also less favourable than those we see in the other Nordic countries, suggesting that the opportunity costs of these countries are lower. Figures on international trade also suggest that Iceland's comparative advantage lies in the fishing industry. This suggests that although it could be assumed that the agriculture industry has multiplier effects, it is considered unlikely that it is a base industry.

In chapter 7.3 it was shown that forestry in Iceland does not make a significant contribution to GDP. For similar reasons as for agriculture, doubt can be cast on forestry being a base industry in Iceland. Thus, multiplier effects of the forest industry will not be considered.

Advanced production using biological resources could be considered a base industry although the primary production cannot. Iceland is rich in other resources which are important for production, e.g. water and renewable energy. Previous research has suggested that the aluminium and energy sector of the economy is a base industry (Ragnarsdóttir, 2012). This allows for consideration that other energy or water intensive

production industries could be considered base industries. No previous research on this topic was found, and it has not been considered under the scope of this analysis. An upper limit for the multiplier effects of food production, other than fish, could be estimated by using the multiplier of the fishing industry. Therefore, total contribution of food production in 2010 would be estimated as 5.2% of GDP, rather than 2% of GDP, as stated in national accounts.

Chapter 7.3 summarised that the direct contribution of the bioeconomy was 13.1% of Iceland's GDP in 2010. If working on the basis that only the fishing industry, or the ocean cluster, can be considered a base industry, the total contribution of the bioeconomy rises to 29.1% of GDP in 2010. This number gives a lower limit for total contribution of the bioeconomy since it has been proven that the fishing industry is a base industry. If upper limits of the multiplier effects for other industries are included, the total contribution rises to 33.7% of GDP. This is an upper limit for total contribution based on the information available.

Taking this information together, a conclusion should be made on whether the bioeconomy can be considered a base industry. The ocean cluster is the biggest part of the bioeconomy, and since it has been proven to be a base industry, it is clear that the bioeconomy has a greater contribution to GDP than national accounts suggest. But it seems also clear that only part of the bioeconomy can be considered exogenous to other industries. It would need further testing to conclude if the bioeconomic industries together are exogenous to other industries. A rough estimate of an upper limit of the total contribution suggests that it could be approximately one third of GDP.

**Table 1: The bioeconomy's contribution to GDP in 2010 for three cases.**

	<b>Direct contribution</b>	<b>Total contribution: Lower limit</b>	<b>Total contribution: Upper limit</b>
<b>Ocean cluster</b>	10%	26%	26%
<b>Agriculture</b>	1.1%	1.1%	2.5%
<b>Forestry</b>	0%	0%	0%
<b>Food production (excluding fish)</b>	2%	2%	5.2%
<b>Total</b>	<b>13.1%</b>	<b>29.1%</b>	<b>33.7%</b>

## 7.5 Dimension reduction

The economic dimensions considered thus far are value added, part of GDP, labour productivity, capital productivity, export value and part of total export value. These dimensions have been analysed over time, industries and countries. What remains to be done is to conclude whether the dimensions of our data can be reduced. A dimension reduction will be considered for data matrices over time, industries and countries, using principal component analysis.

The first PCA is on data concerning the Icelandic bioeconomy over the period 2000-2010. The bioeconomy is considered the aggregate of the fishing industry, aquaculture, agriculture, forestry, food production and advanced production using wood and textiles. Labour productivity is only calculated for agriculture, fishing and fish processing because labour data are missing for other industries. The data are presented in table 13 in the appendix.

Results from the first PCA analysis are shown in table 2. The analysis was done using centred and scaled data. This corresponds to a PCA on the correlation matrix. The result suggests that the dimension of six variables could be reduced to two components which would explain 96% of the variance in the data. The first component can be summarised as the average of variables for value creation, while the second component can be summarised as an indicator of the size of the bioeconomy in relation to the whole economy.

**Table 2: PCA results for economic measures of the bioeconomy over time. Loadings of the first four components and their cumulative proportion of total variance.**

<b>Component:</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
Contribution to GDP	-0.32	-0.57	-0.16	0.19
Value Added	-0.48	-0.16	-0.17	0.21
Labour Productivity	-0.41	0.40	0.11	0.70
Capital Productivity	-0.48	-0.05	-0.50	-0.47
Export Value	-0.48	-0.00	0.79	-0.39
Part of Total Export Value	0.17	-0.69	0.27	0.24
<b>Cumulative proportion of variance</b>	<b>66.9%</b>	<b>96.1%</b>	<b>98.3%</b>	<b>99.2%</b>

The second PCA is on data of bioeconomic industries for the year 2010. The industries considered are agriculture, fisheries, fish processing and other food production. The data available on industries limit both the number of industries for consideration and the number of variables. Here value added, labour and capital productivity of these industries will be considered. Part of GDP is omitted here since it is a scaled version of value added in this case. The data table is presented in table 14 in the appendix.

Results for the second PCA are presented in table 3. Again, the analysis was done using centred and scaled data. The results suggest that using the average of these measurements we can explain over 76% of the variance in the data set. Most of the information left in the data can be shown by contrasting capital productivity to the other two measures. This suggests that capital productivity is in a way different from the other two. The dimensions could be reduced to two and 98% of the variance would be explained.

**Table 3: PCA results for economic measures of bioeconomic industries in 2010. Loadings of the three components and their cumulative proportion of total variance.**

<b>Component:</b>	<b>1</b>	<b>2</b>	<b>3</b>
Value Added	0.59	-0.49	0.64
Labour Productivity	0.64	-0.18	-0.75
Capital Productivity	0.48	0.85	0.20
<b>Cumulative proportion of variance</b>	<b>76.5%</b>	<b>97.8%</b>	<b>100%</b>

The third PCA performed was on data on the bioeconomy of the Nordic countries in 2010. Data available limited both which countries could be used and which variables. Here Iceland, the Faroe Islands, Norway, Sweden, Finland and Denmark are considered. Åland Islands are a part of Finnish data but Greenland is left out on the grounds of lack of data. The bioeconomy could not be considered as a whole and thus only aggregated numbers for primary production within the bioeconomy are presented. The variables used are value added, part of total gross value added, capital productivity, export value and part of total export value. Value added and export value were converted to Euros to

allow comparison. Data on capital stock were not available and thus estimates of gross capital formation were used. The data set is shown in table 15 in the appendix.

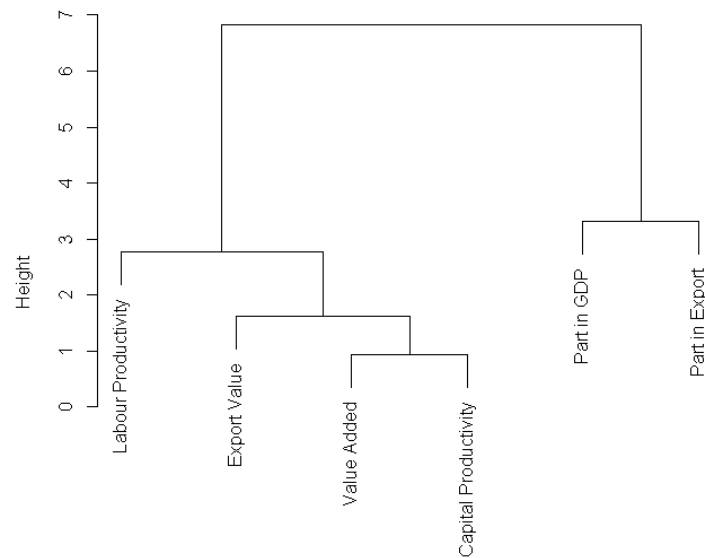
The results of the PCA are presented in table 4. The data was centred and scaled. The first component explains 76% of the variability in the data and over 95% is explained with two components. Although the number of components is in synchrony with the first two PCAs, the loadings of the components differ. The first component shows the contrast of value added to the other variables, with little weight of export value. The second component primarily represents export value. The same PCA leaving capital productivity out was also performed, since capital productivity was not measured in the same manner as previously. This did not have a significant effect on the loadings of the other variables and thus the conclusion would be the same.

**Table 4: PCA results for economic measures of the bioeconomy in the Nordic countries in 2010.**  
**Loadings of the first four components and their cumulative proportion of total variance.**

<b>Component:</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
Contribution to GDP	-0.50	-0.04	-0.42	0.03
Value Added	0.47	0.10	-0.86	-0.11
Capital Productivity	-0.51	0.00	-0.11	-0.77
Export Value	-0.15	0.98	0.02	0.12
Part in Total Export Value	-0.50	-0.17	-0.28	0.61
<b>Cumulative proportion of variance</b>	<b>76.1%</b>	<b>95.1%</b>	<b>99.5%</b>	<b>100%</b>

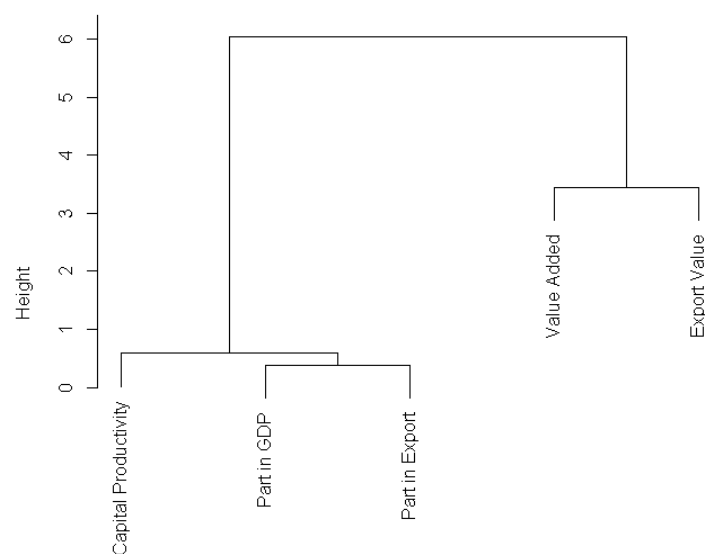
This concludes that the dimensions of valuing the bioeconomy can be reduced, and a proposition for how the dimension reduction could be performed has been suggested. However, to further analyse which variables are connected, a hierarchical cluster analysis is performed using measurements of the Icelandic bioeconomy in the period 2000-2010. The clustering was both performed with, and without, scaling of the variables. Results were similar. The clustering method used was Ward's minimum variance method, described in Chapter Five. The height or distance between clusters thus represents the difference in variance within the clusters. The result shows a clear breakdown into two clusters, as illustrated in figure 19. One cluster showed variables of

the bioeconomy's part of the total economy, while the other showed indicators of value creation within the bioeconomy.



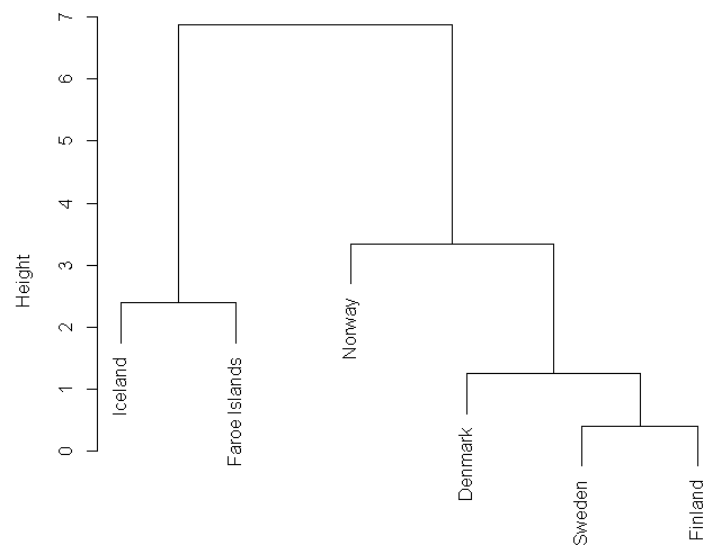
**Figure 19: Cluster dendrogram of economic dimensions of the Icelandic bioeconomy using data over the period 2000-2010.**

Results from the PCA analysis of data on the Nordic countries differed from results on the Icelandic bioeconomy. Therefore, a cluster analysis of the variables was also done using data on the Nordic countries. Two clear clusters were also generated, but not the same clusters, as seen in figure 20. Here, capital productivity forms a cluster with variables on the bioeconomy's part in the economy, and the second cluster is formed by value added and export value; that is variables on value creation.



**Figure 20: Cluster dendrogram of economic dimensions of the Nordic countries bioeconomies in 2010.**

The hierarchical cluster analysis can also be used to form a cluster of data points rather than variables. A cluster analysis of the Nordic countries shows which of the Nordic countries have similar bioeconomies with regards to economic dimensions, shown in figure 21. The cluster analysis shows how different Iceland and the Faroe Islands are from the other Nordic countries, with respect to their bioeconomies.



**Figure 21: Cluster dendrogram of the Nordic countries based on economic dimensions of the bioeconomies in 2010.**

The analysis performed in this chapter shows that the economic dimensions of the bioeconomy could be reduced but these dimensions differ between datasets. We also show how the Nordic countries differ from one another with respect to economic dimensions of the bioeconomy. The last cluster dendrogram also shows how unique the bioeconomy of the Arctic area is.



## 8 Discussion

The first goal of this analysis was to define the bioeconomy and consider why it is interesting. The definition chosen indicates that the bioeconomy encompasses the whole value chain from utilising renewable biological resources. Thus all economic activity connected to biological resources is included in the bioeconomy. The renewable biological resources are of special interest, since they can be utilised in a sustainable manner. Resource scarcity and increasing world population have introduced problems in ensuring future generations have the same, or greater, welfare than we have today. Therefore, it is clear that renewable resources will be of increased importance for future generations. The problem is to find a way for renewable resources and man-made capital to increasingly replace the utilisation of non-renewable resources. The bioeconomy provides a tool for finding the solution, since it encompasses the resources and economic activity that need an increased emphasis to ensure the welfare of future generations.

The term 'bioeconomy' has some limitations. It defines a part of the economy that is of special interest for the development of our economy. However, it does not suggest operations or specific goals that would lead us to a solution to the welfare maximisation problem for future generations. It is also clear that a full understanding of the welfare possibilities of future populations is not reached by considering one country at a time. A more integrated approach should be used, in order to draw conclusions on possibilities of sustainable development where specialisation between countries is taken into account.

The second objective of the analysis was to consider economic indicators for the bioeconomy. The aim was to analyse value creation and the efficiency of economic activity within the bioeconomy, in addition to considering the bioeconomy's contribution to the total economy. The indicators were chosen on grounds of economic theory. The sustainability dimension of the bioeconomy was considered but not measured directly. The bioeconomy is a concept that needs an interdisciplinary approach, and as such, other dimensions to the bioeconomy should be considered. For

example, measurements of sustainability, employment, rural development and resource productivity could increase our understanding of the bioeconomy.

Six economic dimensions were considered but results from tests on dimension reduction indicated that the economic dimensions could be reduced to two. Results from cluster analyses of the dimensions indicate that these two dimensions are value creation and contribution to the total economy. Theoretically, the most correct indicator for value creation is value added, measured on market prices. For contribution to the total economy, the most correct indicator is contribution to GDP. These results indicate that for future analysis, data on all dimensions will not be needed. Gathering data on value added and contribution to GDP should give sufficient information on the economic dimensions of the bioeconomy. However, this result is built on a relatively small dataset, a short time series, and should, as such, be interpreted with caution. In order to strengthen this result, a similar analysis could be done for other countries or a longer time series, or both. When the third dimension is needed, the results suggest including export value as an indicator of specialisation.

The third, and final, goal of the analysis was to analyse the Icelandic bioeconomy. Looking at the results for the Icelandic bioeconomy, what is obvious is the importance of the marine sector to the whole economy. The direct contribution of the bioeconomic industries considered was around 13% of GDP, of which nearly 10% of GDP was from the marine sector. The fishing industry has been shown to be a base industry, and its total contribution to GDP has been estimated at 26%. The fact that value creation is much greater within the marine sector than from biological resources on land is in synchrony with data on quantity of biological resources. Little opportunities exist for utilising biological resources on the land in Iceland, but the Icelandic nation has good accessibility to rich fishing grounds. The utilisation of marine resources has been performed in a sustainable manner since the catch rule was introduced. Resources of the land have not been utilised sustainably, but this is the long term aim.

The Icelandic bioeconomy's part in the whole economy is relatively large compared to other Nordic countries. The Faroe Islands and Greenland have even larger parts of their economies created by the bioeconomy, but the bioeconomies of other Nordic countries are much smaller by comparison. Here, we should note that numbers used to

compare the Nordic countries only include primary production. Therefore, the greater role of the bioeconomy in the Faroe Islands, Greenland and Iceland suggests that these three countries have less advanced economies than the other Nordic countries. In order to draw better conclusions on the Nordic countries, derived production should also be considered. This can be done by considering the multiplier effects, or by gathering data on bioeconomic industries.

Biological resources on land in Iceland are much less than those found in other Nordic countries, excluding the Faroe Islands and Greenland. The comparative advantages of Iceland, the Faroe Islands and Greenland lie in the marine sector. All three countries have good access to rich fishing grounds, and the Faroe Islands have built up a big aquaculture industry. Nonetheless, when comparing weights of marine catch, those of Iceland, the Faroe Islands and Greenland are small compared to the Norwegian catch, which is almost twice as large as the Icelandic catch. The aquaculture sector in Norway is also significantly larger than that in other Nordic countries. Taking this together, we see that although we have good opportunities in the marine sector in Iceland, we are still producing much less than Norway, which is rich in natural resources.

The analysis provides a good map of the Icelandic bioeconomy, but has some limitations. The sustainability of the bioeconomy was not analysed thoroughly. The main reason for considering the bioeconomy separately from other economic activity is because it encompasses renewable resources that have the possibility of being utilised sustainably. Thus, further analyses should be conducted to consider the sustainability criterion for the Icelandic bioeconomy.

Some data problems have restricted our analysis. Our first aim was to collect data based on species for all biological resources. This proved to be not possible, since most data is only available by industry type, and industries almost always utilise more than one species. Also, when collecting quantity data on biological resources, we were unsuccessful in generating comparable measurements for different species. Calculating biomass for different species could be a solution to this, but both the nutritional and economic value per tonne differs between species. Also, in order to calculate biomass,

we would need stock estimates for all wild species, on land and in the sea. This kind of data is not currently available and would be expensive to collect.

Natural resources should be considered as an input into the aggregate production function, introduced in Chapter 3.2. They are generally not accounted for in capital because property rights are often not defined. This implies that resource productivity could also be considered as a measure of efficiency. Data on biomass over a number of years would be needed for this calculation. Thus, our data problems limit the analysis again here. We do not have biomass for all biological resources, and when these are available they are generally only available for one or a few years. Resource productivity could be calculated for industries where this data is available, and compared between countries to analyse differences in efficiency. This was considered outside of the scope of this analysis, but provides an opportunity for future analysis.

One of the incentives connected with the bioeconomy is the opportunity to reduce the use of fossil fuels by increasing the use of bio-fuels. This aspect of the bioeconomy has not been under consideration for this paper. The main reason for that is that in Iceland, over 85% of energy consumed is from renewable resources (Source: Statistics Iceland). Therefore, there is little need to increase this. Also, Iceland has little opportunity to produce what is needed for bio-fuel production, since crop production is small and arable land is only a small part of the total land area. In the European Union, on the other hand, only 13% of energy consumed is from renewable resources (Source: Eurostat). Their aim is to increase the contribution of renewable energy to total energy consumption by increasing bio-fuel production and usage.

In summary, the analysis conducted has answered the questions it set out to answer. However, the process of going through the analysis has raised many new questions. Further analysis will be needed to answer these questions and bring us closer to a sustainable and efficient bioeconomy.

## 9 Conclusion

This analysis set out to answer three research questions. The first of these considered defining and interpreting the term bioeconomy. Through reviewing former work on the bioeconomy, the definition chosen was based on work done by the European Commission. The bioeconomy is considered to encompass all economic activity connected with utilising renewable biological resources. The interest in the bioeconomy is connected to the renewability of the resources and the possibility of managing their utilisation sustainably. Other resources do not offer this possibility of ensuring the welfare of future generations.

The second question considered what the economic dimensions of the bioeconomy are. The analysis went through some economic theory to introduce the indicators chosen; value added, contribution to GDP, productivity and international trade. Using data on the Icelandic bioeconomy, we were able to conclude that the economic dimensions could be reduced from six to two. The theoretical best-fit indicators for these dimensions were value added and contribution to GDP. The theory of base industries was introduced. According to this theory, some industries can have bigger contributions to the economy than national accounts suggest. If an industry is considered external to other industries and has additional contribution to the economy, it can be considered a base industry. The total contribution of a base industry to the economy is the aggregate of its direct and derived contributions.

The third and final consideration was to describe the Icelandic bioeconomy. This included identifying the biological resources available and collecting data on the economic dimensions of the bioeconomy. The results showed that the Icelandic bioeconomy is highly dependent on the marine sector, which has been shown to be a base industry. The direct contribution of the Icelandic bioeconomy to GDP was estimated to be 13%, while total contribution was estimated at around 30%. Comparing the Nordic countries shows that Iceland, the Faroe Islands and Greenland appear to be more dependent on primary production from the bioeconomy than the other Nordic

countries. These three also have in common the fact that their bioeconomies are mainly built on the marine sector, with little possibilities for biological resources on land.

This analysis is restricted in several aspects. Firstly, it only partly considers the sustainability of the bioeconomy. Secondly, it has pointed out that further analysis should be on an international level, rather than a national level. This is mainly because of specialisation and the comparative advantage of individual nations. Thirdly, the bioeconomy is an interdisciplinary phenomenon and, as such, should be analysed with an interdisciplinary approach. This analysis contributes to the economic dimensions of the phenomenon, but other dimensions might be of interest.

The bioeconomy is a new phenomenon, and as such needs further research. The term is still in development and does not yet have a clear definition. In addition, the objectives related to developing the bioeconomy are unclear. It is necessary to outline what the objectives are, and also what the indicators for progress are. Here, economic indicators have been suggested and analysed, but similar work is needed in other fields.

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## Appendix – Data

**Table 5: Iceland land cover classification according to CORINE for the year 2006  
(Árnason & Matthíasson, 2009)**

Land cover class	Area, km <sup>2</sup>
<b>Artificial surfaces</b>	396
<b>Agricultural areas:</b>	2,523
Non-irrigated arable land	21
Pastures	2,452
Complex cultivation pattern	50
<b>Forest and semi-natural areas</b>	90,661
Broad-leaved forest	229
Coniferous forest	17
Mixed forest	68
Natural grassland	2,885
Moors and heathland	35,985
Transitional woodland/shrub	264
Beaches, dunes, and sand plains	3,169
Bare rock	23,694
Sparsely vegetated areas	13,451
Glaciers and perpetual snow	10,901
<b>Wetlands</b>	7,476
<b>Water</b>	2,386

**Table 6: Area covered by forests in Iceland (Traustason & Snorrason, 2008)**

	Area (km <sup>2</sup> )
<b>Natural birch forests</b>	<b>1,155.0</b>
Natural birch forest; over 2 m height	236.5
Natural birch bushes; under 2 m height	918.5
<b>Cultivated forests</b>	<b>413.5</b>
Forests; over 2 m height	112.7
Broad-leaved forests	5.8
Coniferous forests	24.3
Mixed forests	82.7
Reforestation areas	300.8

**Table 7: Numbers of birds hunted in Iceland 2010 (Source: The Environment Agency of Iceland)**

	Numbers
Ptarmigan	73,929
Goose species	67,933
Guillemots	35,182
Puffin	34,369
Gull species	27,651
Duck species	17,471
Razorbill	15,257
Other birds	11,695
<b>Total</b>	<b>283,487</b>

**Table 8: Numbers of caught fresh water fish in 2010 (Source: Institute of Fresh Water Fisheries)**

	Salmon	Sea trout	River trout
Angling	74,961	48,798	33,514
Of which released	21,476	7,841	2,397
Net fishing	15,903	-	-
<b>Total fishing</b>	<b>90,864</b>	<b>48,798</b>	<b>33,514</b>
<b>Total catch</b>	<b>69,388</b>	<b>40,957</b>	<b>31,117</b>

**Table 9: Catch of the Icelandic fleet in 2010 by catch category and main species in tonnes and percentage of total catch (Source: Statistics Iceland)**

Catch category	Catch, tonnes	Catch, percentage
<b>Demersal fish</b>	430,367	40.5%
<i>Cod</i>	178,516	16.8%
<i>Haddock</i>	64,948	6.1%
<b>Flatfish</b>	24,198	2.3%
<b>Pelagic fish</b>	595,653	56.0%
<i>Herring</i>	254,473	23.9%
<i>Capelin</i>	114,100	10.7%
<b>Shellfish</b>	10,627	1.0%
<b>Other</b>	2,623	0.2%
<b>Total catch</b>	<b>1,063,467</b>	<b>100.0%</b>

**Table 10: Stock abundance in millions, spawning stock biomass in thousand tonnes and fishable stock biomass in thousand tonnes (Source: Marine Research Institute)**

	Stock	SSB	FSB
Cod	883	298	840
Capelin	93,600	402	-
Haddock	224	116	169
Saithe	98	96	186
Nephrops	-	-	17

**Table 11: Slaughtered fish from Icelandic aquacultures (Source: The Icelandic Aquaculture Association)**

	2010	Average 2008-2012
Atlantic Salmon	1,011	1,269
Arctic Char	2,390	2,913
Rainbow trout	48	144
Halibut	70	31
Turbot	53	38
Cod	1,240	1,102

**Table 12: Production of/from resources in the agricultural sector in Iceland 2010**  
(Source: Statistics Iceland and the Icelandic Food and Veterinary Authority)

	Sheep	Cattle	Horses	Swine	Poultry	Vegetables	Cereals
<b>Livestock size / Field area, km<sup>2</sup></b>	479,605	73,781	77,196	3,615	323,414	20	55
<b>Biomass [tonnes]</b>	25,378	26,795	21,452	813	383		
<b>Production [tonnes]</b>	9,166 <sup>18</sup>	134,000 <sup>19</sup>	799	6,158	9,768 <sup>20</sup>	18,484	13,175
<b>Output value [million ISK]</b>	8,856	15,430	677	1,675	3,566	11,587	444
<b>Export value [million ISK]</b>	2,752	630	988	24	3	5	8

**Table 13: Economic dimensions of the Icelandic bioeconomy, 2000-2010 (Source: Statistics Iceland)**

Year	Contribution to GDP, %	Value Added	Labour Productivity	Capital Productivity	Export Value	Part in Total Exports, %
<b>2000</b>	14.4	150,979	5.949	0.432	182,626	67.1
<b>2001</b>	16.4	187,192	7.933	0.498	219,152	65.2
<b>2002</b>	15.0	173,001	7.806	0.487	219,832	65.9
<b>2003</b>	12.8	148,835	7.152	0.433	191,469	65.6
<b>2004</b>	11.2	135,688	6.939	0.414	198,702	63.4
<b>2005</b>	10.1	128,708	6.616	0.420	171,717	59.4
<b>2006</b>	10.0	135,234	7.341	0.428	181,887	53.8
<b>2007</b>	9.1	133,256	7.728	0.431	177,236	43.8
<b>2008</b>	10.2	154,526	10.581	0.440	213,454	38.7
<b>2009</b>	14.0	195,293	12.979	0.530	232,124	44.0
<b>2010</b>	13.4	181,408	11.068	0.520	235,278	41.9

<sup>18</sup> Production does not include wool production. The value of wool output, 428 million ISK, is included.

<sup>19</sup> Includes both production of meat, 3.895 tonnes, and milk, 130.105 tonnes.

<sup>20</sup> Includes both meat production, 6.905 tonnes, and egg production, 2.863 tonnes.

**Table 14: Economic dimensions of Icelandic bioeconomic industries in 2010 (Source: Statistics Iceland)**

Industry	Contribution to GDP, %	Value Added	Labour Productivity	Capital Productivity	Export Value	Part in Total Exports, %
Agriculture	1.1	14,890	3.04	0.206		
Forestry	0.0	87		0.003		
Fisheries	6.5	87,874	16.58	0.619		
Aquaculture	0.1	1,785		0.329		
Fish processing	3.4	46,571	14.11	0.971	201,494	35.9
Other food production	2.0	26,397	3.15	0.660	30,521	5.4
Textile etc. production	0.2	2,402		1.053	2,679	0.5
Wood and paper prod.	0.1	1,397		0.100	582	0.1

**Table 15: Economic dimensions of bioeconomies of the Nordic Countries in 2010 (Source: Nordic Council of Ministers)**

Country	Contribution to GDP, %	Value Added <sup>21</sup>	Labour Productivity <sup>22</sup>	Capital Productivity	Export Value <sup>23</sup>	Part in Total Exports, %
Iceland	7.7	646	81,252	0.537	31,720	41.6
Greenland					538	89.8
Faroe Islands	16.8	254		0.835	25,334	90.3
Norway	17.3	4,844	99,586	0.080	52,445	8.2
Sweden	1.7	5,045	56,843	0.080	521	14.3
Finland	2.9	4,486	46,535	0.130	2,398	19.2
Denmark	1.3	2,634	49,518	0.066	1,096	21.6

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<sup>21</sup> Million Euros

<sup>22</sup> Euros per Employed Person