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Examining the potential economic impacts of Scottish offshore wind developments

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Declaration of Authenticity and Author's Rights

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

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Date

Abstract

Since the turn of the century there has been significant change in Scottish energy policy, with climate change mitigation being a key objective. To meet policy objectives the Scottish Government has set out a wide range of targets with the most ambitious being to meet the equivalent to 100% of gross electricity demand from renewables by 2020. With Scotland having the highest offshore wind resource in Europe (25% of the total) it is expected that offshore wind will be important in reaching this target, and there are currently several wind farms in development. Recently there has been a focus on the possible economic development resulting from large scale renewable projects. This is the primary motivation of this thesis – examining the potential economic impacts arising from the development of Scottish offshore energy wind capacity.

In this thesis there are six chapters, with the first being an introduction to Scottish energy policy; the evolution to the electricity network, and wind energy in Scotland. The purpose of this chapter is to provide the reader with the necessary background to understand the context of this thesis.

Chapter 2 details the development of an Electricity Satellite Account (ElSA) framework, from which we create an ElSA for Scotland for 2012. Satellite accounts have been used extensively to improve the System of National Accounts (SNA) by extending the analysis of sectors which are not well represented in that framework (with the most common satellite account being for tourism). In the standard SNA framework the electricity sector is represented by a single sector which incorporates generation, transmission, distribution and sales, raising a number of problems for meaningful economic analysis. The development of an ElSA allows a better understanding of the interactions between electricity generation and consumption and the economy. This is the first attempt (to our knowledge) to develop an ElSA has been development and as such we take elements of the Tourism Satellite Account (TSA) framework and modify these to develop a satellite account for the electricity sector in Scotland.

The development of an ElSA not only allows for a better understanding of the linkages between the electricity sector and the economy, it can be used to disaggregate the electricity sector within the IO tables – data which in turn feeds into a number of popular macroeconomic models. This is the focus of Chapter 3. The disaggregation of the electricity sector is not new endeavour, there are several examples of this being carried out. However the contributions of this chapter is that, using the ElSA information, we develop and apply a "hybrid" methodology which accounts for the variations in electricity price. There are examples in the literature noting the problem disaggregating based on volume of electricity (Jones et al, 2010; Algrain et al 2014) and this is the first known attempted of accounting for the variation.

In Chapter 4 the disaggregated IO table from Chapter 3 is used to create an IO model which is used to investigate the macroeconomic impacts from the development of offshore wind capacity in Scotland. Several different scenarios – single farm; planned capacity and future growth - are modelled in this chapter with particular attention paid to the local content (an increasingly important policy issue). The two contributions of this chapter are the investigation on the cumulative economic impacts of planned Scottish offshore wind developments and the impact of changes in local content.

IO models have well known assumptions– most notably a passive supply side and fixed prices. In Chapter 5 we relax these assumptions by using a CGE model based on the AMOS framework with disaggregated electricity sector, which again uses the disaggregation from Chapter 3. This AMOS framework allows for the impacts of many more variables (compared to IO) to be examined and we use this model to simulate the same scenarios as Chapter 4. The contribution of this chapter is that this is the first time the economic impacts of development of offshore wind energy capacity in Scotland have been modelled through a CGE framework.

Finally, the thesis concludes in Chapter 6 with detail of potential avenues of future work.

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List of Abbreviation

AMOS – A Macro – Micro Model for Scotland

BEIS – Department for Business, Energy and Industrial Strategy

BM – Balance Mechanism

BOA – Bid Offer Acceptance

BRES – Business Register and Employment Survey

CAPEX – Capital Expenditure

CB – Cobbs Douglas

CES – Constant Elasticity of Substitution

CGE - Computable General Equilibrium

CO_2 – Carbon Dioxide

COE – Compensation to Employees

CSTE – Cost of Electricity

CfD – Contracts for Difference

ElSA – Electricity Satellite Account

EU – European Union

FPN – Final Physical Notification

GB – Great Britain

GDP – Gross Domestic Product

GPR – Gross Regional Product

GVA – Gross Value Added

GW – Gigawatt

GWh – Gigawatt hour

IxI – Industry by Industry

IO - Input-Output

LCA – Life Cycle Assessment

LCOE – Levelised Cost of Energy

MW – Megawatt

MWh – Megawatt hour

NI – Northern Ireland

NG – National Grid

NPV – Net Present Value

O&M – Operation and Maintenance

OECD – Organisation for Economic Co-operation and Development

ONS – Office for National Statistics

OPEX – Operational Expenditure

OTM – Offshore Transformer Module

POE – Price of Electricity

RGB – Rest of GB

ROCs – Renewable Obligation Certificate Scheme

RSPB – Royal Society for the Protection of Birds

SAM – Social Account Matrix

SIC – Standard Industrial Classification

SNA - System of National Accounts

SNP – Scottish National Party

TSA – Tourism Satellite Account

UK – United Kingdom

UN – United Nations

Chapter 1 – Introduction to the thesis

The primary objective of this thesis is an investigation of the potential macroeconomic impacts resulting from the development of offshore wind capacity in Scotland. In this thesis, before any economic impacts are assessed, we first extended the analysis of the electricity sector within the System of National Accounts (SNA). The motivation for this analysis can be rooted to two key quotes:

"Scotland has 25% of all European wind resource" (Scottish Government, 2011a)

"To reindustrialise Scotland through 21st century technologies and seize the opportunities to create tens of thousands of new jobs and secure billions of bounds of investment" (Scottish Government, 2011a)

For a relatively small nation Scotland has an abundance of natural offshore wind resource which, if exploited, has the potential to have a substantial positive impact on the economy.

To date (2018), the development of Scottish offshore wind has been painstaking slow with only one fixed offshore windfarm currently operational. There are however several offshore windfarms in development/planning which may become operational by 2027[1]. In this PhD we take both an Input-Output (IO) and Computable General Equilibrium (CGE) modelling approach to investigate the potential cumulative impacts of these offshore wind developments on the Scottish economy.

Also, it is the contention of this thesis that we extend the analysis of the electricity sector within the SNA by developing an Electricity Satellite Account (ElSA). This ElSA not only contains information on the electricity sector, it is also used to disaggregate the electricity sector within IO tables. As both IO and CGE modelling use information contained within these tables, the disaggregation is ultimately used in the investigation of the economic impacts of Scottish offshore wind.

[1] A full list of these windfarms can be found in Appendix 1A

In this chapter we describe the energy policy landscape which is driving changes in the Scottish electricity system, followed by a detailed discussion of the relationship between the economy and offshore wind and other renewable technologies. Finally this introductory chapter finishes with a detailed breakdown of the later chapters and their contributions.

1.1 Scottish Energy Policy

Under the Scotland Act (1998), the Scottish Parliament has the power to legislate in all matters other than those specifically ‘reserved’ to the UK Parliament. The generation, transmission, distribution and supply of electricity remain one of these reserved matters. However, through the 1989 Electricity (Scotland) Act the Scottish Parliament has the ability to grant or withhold planning consent of overhead transmission lines and generation stations over 50MW – apart from offshore wind (Royles and McEwan, 2015)[2]. This gives the Scottish Parliaments a level of autonomy in shaping a devolved energy policy.

Since devolution, with the emergence of new technologies and a greater understanding of the causes and effects of climate change, there has been significant change in Scottish energy policy – with post 2000 policy placing a large emphasis on a ‘greener’ Scotland through the Climate Change Act (Scottish Government, 2009). The root of this ‘greener’ energy policy can be attributed to the Kyoto agreement of 1997. This agreement was the first of its kind, with most countries[3] agreeing to cut CO_2 emissions. In the agreement it was stressed than the larger, developed countries must do more than their developing counterparts.

Since this agreement there has been a worldwide emphasis placed on climate change mitigation, reflected – in the EU - with the introduction of 2020 targets. These are EU-wide commitments to reduce the greenhouse gas emissions (from 1990 levels) by 20% while increasing energy efficiency by 20% and producing 20% of all energy from renewables. With these targets being EU-wide they are country dependant, some countries have higher targets

[2] Where they have power over planning consent for generation over1MW instead of 50 MW for offshore wind

[3] The only exceptions being the Sudan, Afghanistan and the USA.

and other have lower ones so that the full EU group of nations will achieve the goal. The UK makes use of these flexible targets by setting targets for a 34% reduction in greenhouse emissions (UK Government, 2008), which is higher than the overall EU target but the renewable energy target is set 5% lower at 15% by 2020 (European Commission, 2009).

The current 2018 Scottish Government has adopted more stringent targets for emission reduction and renewable energy generation than the UK Government. By 2020 Scotland has the target to reduce greenhouse gas emissions by 42% percent (Scottish Government, 2009) which is 8% higher than that for the UK as a whole. However, the Scottish Government has still set the same 80% reduction in greenhouse emissions by 2050 as the UK government[4]. The 80% target reflect the view of a technical standpoint that it is will be extremely difficult to reduce emissions by more this. One reason why the Scottish Government has targeted a greater reduction in CO_2 emissions compared to the UK government by 2020 is the abundance of renewable energy resources which Scotland has. Not only has Scotland a large capacity for wind energy but there is also a large potential for marine renewables and already a large quantity of hydro installed. Indeed by 2015 Scotland was well on the way to meeting its 2020 target with a 37.6% reduction in CO_2 emissions compared with 1990 (Scottish Government, 2017a). Also, Scotland benefits from being a small part of a large grid, so need not worry about grid balancing.

Initially to meet its targets the Scottish Government set out a road map to 2020 detailing the ways in which this 42% emission reduction target would be achieved (Scottish Government, 2011). By far the most ambitious target set in this route map was for the equivalent of 100% of Scottish gross electricity consumption to be generated in Scotland from renewable resources by 2020. There are both likely to be economic and technical consequences of setting such a large renewables target. At the end of 2017 68.1% of Scottish gross electricity consumption was met by renewables (Scottish Government, 2018).

To meet this ambitious 100% gross electricity target it was expected that offshore wind would play a major part, with some estimates suggestions that there could be of up to 5GW of

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[4] The Scottish Government also publishes yearly CO_2 emissions targets (Scottish Government, 2016).

installed capacity by 2018 (Offshore Wind Industry Group, 2011). As we outline in Section 1.3, the development of Scottish offshore wind has been much slower than initially anticipated.

Further to the 100% gross electricity target the Scottish Government have set some other targets which should support the reduction in greenhouse gas emissions by 2020. They have set a target for 30% of overall energy (electricity, transport, heat) consumption to be met by renewables, and with at least of 11% of heat demand to be met by renewable sources. Secondly, for energy efficiency policy, a target of a 12% reduction in energy consumption (Scottish Government, 2011a). This consumption reduction is most likely to come from the domestic sector through the introduction of higher building standards for new build stock and retro-fitting older housing stock. Finally, a target has been established that at least 1GW of new capacity renewable electricity has to be community owned by 2020[5]. While this is not directly supporting a reduction in emissions, it is argued that there will be community and economy benefits of such a scheme[6].

As well as the promotion of renewables through policy, the SNP government in power in 2018 stated that they will not consent any new nuclear power stations to be built in Scotland. This is in conflict with the stance of the 2018 Westminster Conservative Government where the creation of new nuclear is actively encouraged. For example Hickley Point was approved in 2016, and is scheduled to begin generating in 2025. As a result of this policy the two operational nuclear power stations in Scotland (Hunterson and Torness) have seen their operational lifetimes extended. Hunterson B – opening in 1976 - was originally marked to operate until 2011 but over time this has been gradually increased to 2023, the initial scheduled closure of Torness which has also had its lifetime extended by seven years to 2030.

The defined closure of these nuclear plants is no small matter as in 2016 they generated 42.95% (BEIS, 2017a) of Scottish electricity. One potential issue with these closures, as identified previously, is that in the absence of new capacity in Scotland and/or significant reduction in demand, there will be an increased reliance on imports of electricity from the rest of the UK.

[5] The latest Scottish Statistics show that there is currently 670 MW of community owned renewable capacity (Scottish Government, 2018a).
[6] One such success full scheme is based in Fintry whereby the money raised from the ownership of part of a wind turbine is reinvested in the local community.

These nuclear power stations are primary baseload stations, constantly operating with very little variation from near full capacity. If the existing 2018 nuclear generation capacity is replaced by renewable generation capacity there will be a substantial increase in electricity imports required meet Scottish electricity demands.[7] This is been taken into account in planning grid infrastructure with the recent 2018 upgrade on the network with the Western Link project allowing for an extra 2,200MW of electricity to flow between the Scottish network and the England and Wales network (Gill and Bell, 2017).

A recent (2017) development in Scottish energy policy was the development of the Scottish Energy Strategy, investigating the changes needed in the energy sector in the long term to meet the 2050 targets. This strategy was developed with consultation of many experts throughout the sector and takes a “whole-systems approach”. By far the most interesting – for the purpose of this thesis – is the idea of energy productivity. In the past the focus has solely been on energy efficiency and reductions in consumption. However, energy productivity links the energy use to the output of the economy – i.e. how well is the energy being used to produce output. This measurement requires information on the relationship between energy and the economy – one of the motivations in the development of an Electricity Satellite Account in Chapter 2.

1.1.1 The energy trilemma

The original energy trilemma are the three core dimensions on which energy sustainability is measured (World Energy Council, 2016): energy security, energy equity and environmental sustainability. The trilemma suggests that when developing sustainable energy policy, it is advantageous to consider these dimensions to meet the policy objectives. .

Comparing the Scottish 100% gross electricity target to this trilemma we find that there are both positive and negative impacts. Environmental sustainability is the most obvious positive

[7] In 2012 Scottish electricity imports was 3.65% of exports to England (BEIS, 2017b).

with the replacement of generation from ‘dirty’ fossil fuel burning plants with generation from much ‘greener’ renewables sources[8].

The introduction of the 100% renewable target will have both positive and negatives in terms of security of supply. The positive with renewable generation, after construction, all assets needed for generation (e.g equipment, fuel source) are within Scotland. Whereas fossil fuel plants rely on imported fuel, these are potentially affected by changes in the political and economic climate. However adversely, many renewable energy generators rely on intermittent fuel sources (wind, tides, sun etc) and are seen as non-despatchable. With despatchable plants (coal, gas, etc) the output is driven by electrical demand with the level of input fuel changed to adjust electrical output. However, for non-despatchable plants the output is determined by the resource and electricity must be utilized when available[9].

This increased reliance on intermittent fuel sources along with the closure of baseload plants (i.e Cockenzie and Longannet) lowers the security of Scottish supply due to an inevitable increase in electricity imports, during times of high demand and unfavourable weather conditions to ‘keep the lights on’.

Finally, in regards to the energy trilemma there is an expected (at least short term) increase in the cost of electricity (CSTE). BEIS (2016a) publish figures on the estimates for projects CSTE, and while the costs of onshore wind are comparable with fossil fuel technologies there is still a substantial difference between the LCOE onshore and offshore wind. However, there is a lot of research being carried out on reducing the CSTE (especially O&M) for offshore wind so there is hope, as happened with onshore wind, that the cost of offshore wind will in time be competitive with traditional power plants (Dalgic et al, 2015).

In the next section we investigate the evolution of the Scottish electricity network since the turn of the century through ‘greener’ energy policies.

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[8] Not accounting for the substitution of peak demand in Scotland fossil fuel imports

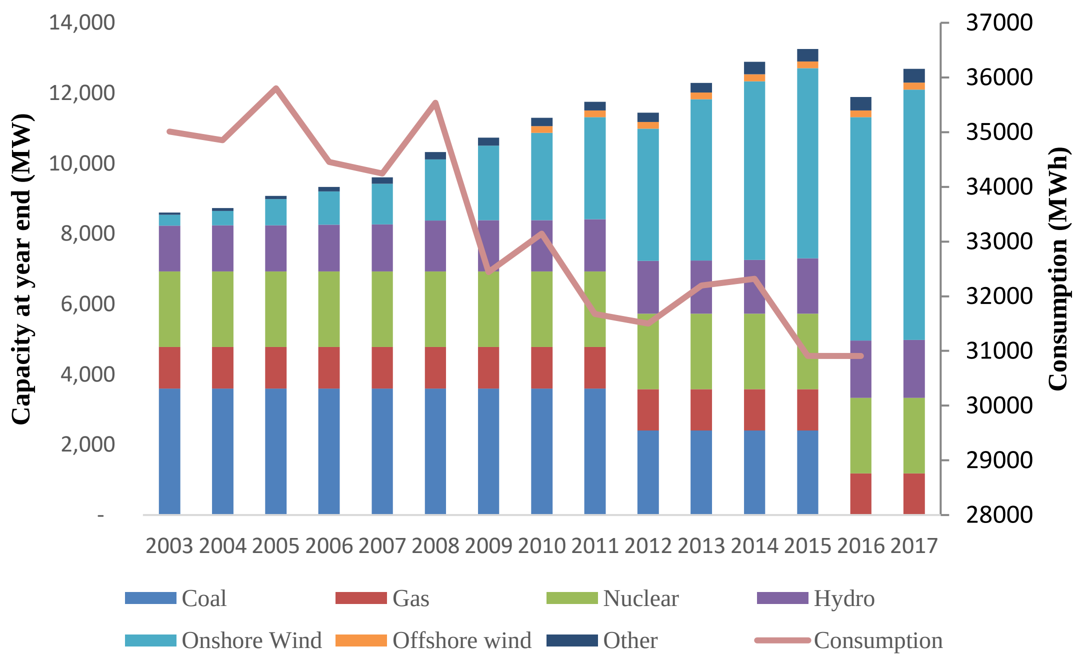
[9] This use of intermittent fuels sources explains the focus in the Scottish Government’s target on 100% gross electricity instead of meeting 100% of demand from renewable sources at all points in time.

1.2 The Evolution of the Scottish Electricity Generation Mix

The previous section detailed the recent changes in Scottish energy policy, which has led to dramatic changes in the electricity network since the turn of the century. In this section we investigate these changes in the network. As well as the policies that have led to changes in the electricity mix.

During the latter part of the 1900s Scotland was reliant on fossil fuel plants – particular coal with 8 operational plants built during the 1970s. However, with the growing realisation of man-made climate change and Scotland's large natural resource, over the years there has been a rise in renewables on the system. Figure 1.1 illustrate the changes over the last 14 years.

Figure 1.1: Evolution of Scottish generation capacity.



Source: Scottish Government (2018a)

In general, between 2003 and 2017 there has been a gradual increase in Scottish electricity generation capacity, with the outliers being 2012 and 2016. As identified earlier, one key areas of energy policy for the Scottish Government was for phase out of coal generation – with the last two coal power stations closing in 2012 and 2016. Between 2005 and 2017 Scottish generation capacity increased by 31% while the consumption of electricity decreased by 10.6% between 2005 and 2016 (Scottish Government, 2018a). The reduction in consumption of electricity can be attributed mainly to increasing energy efficiency measures.

Figure 1.1 demonstrates that there has been a clear shift towards renewable capacity, driven by a more than a 2300% increase in offshore wind capacity over this 14 year period (with wind being the focus on the next section). Historically, renewable energy technologies have a higher cost of generation than fossil fuel plants, thus the UK Government established renewable incentive schemes to aid in their development. Over the years these incentive schemes have changed with three significant policies listed below.

Renewable Obligation Certificate Scheme (ROCs) – Introduced in 2002 with the goal of increasing the proportion of renewable electricity on the network. Under this scheme electricity suppliers must prove that a certain amount of electricity (based on targets) has been generated through renewables sources. This is achieved through the purchase of ROCs (at the set buyout price) from accredited generators (Grimwood and Ares, 2016). With these ROCs the generators were guaranteed additional income per MWh – other than sales on the wholesale market – for 20 years. Initially all ROCs were treated equally however, in a bid to promote less mature technologies, 'banding' was introduced whereby less mature technologies received a higher number of ROCs per MWh. With the substantial increase in renewable deployment since 2002 there was a large increase in costs. This lead to the closure of the ROC scheme for all new renewable generators in 2017[10], replaced by the contracts for difference scheme, which we introduce shortly. While the principle is the same, the Scottish ROC scheme is separate from the rest of the UK.

Feed in Tariffs (FiTs) – Aimed at increasing micro generation, the FITs scheme was introduced on the 1st April 2010 for projects of up to 5MW covering the following technologies: wind, solar photovoltaic (PV), hydro, anaerobic digestion (AB) and 2kW for

[10] ROCs closure was earlier for PV and wind in 2015/16 and 2016 respectively.

combined heat and power (CHP) (Ofgem, 2017)[11]. The owner is paid through two different tariffs – a generation tariff and export tariff. With the generation tariff the energy supplier pays the owner a set price (which is technology specific)[12] for each unit of electricity generated, while the export tariff is an additional payment the owner receives from the energy supplier for each unit of electricity exported onto the grid. FITs scheme have been implemented worldwide but one key problem is that the increased cost from the energy suppliers is passed on to consumers on the network as a renewable energy promotion cost (del Rio and Gual, 2007). This is a problem as the prices of consumers are being driven up even though they may not see the benefit of the scheme.

Contracts for difference (CFD) - Part of the Energy Act of 2013 (UK Government, 2013) was the electricity market reform (EMR) to encourage the development of renewable technologies. This had two key mechanisms – the introduction of contracts for difference and a capacity market. The CfD is seen as the direct replacement for the ROCs scheme and is intended to decrease the cost to consumers through lowering the cost of electricity through competition, while provided long-term financial stability to project developers. A CfD is an agreement between the generator and Low Carbon Contracts Company (LCCC) -owned by the Government - whereby the generator is paid the difference between the strike price (based on the cost of generation) and the reference price (based on the electricity market price). This reduces the uncertainty in income for the generators however, if the reference price is greater than the ‘strike’ then the generators must reimburse the LCCC the difference. This is desirable for developers as they have a steady stream of income whereas government know exactly the price that will be paid for electricity.

One anticipated outcome of the CfDs scheme is the reduction in the cost of electricity, which is achieved through the use of competitive auctions. Only a certain amount of renewable energy capacity will be awarded a CfD in each round of auction thus the developers must reduce their cost of electricity to be competitive. This reduction in cost has already been found in the offshore wind sector through each round of CfD auctions – with the most recent case

[11] https://www.ofgem.gov.uk/environmental-programmes/fit/about-fit-scheme
[12] The UK FIT rates (p/kWh) in 2018 are: PV 0.19-4.15, AB 1.57-4.45, CHP 13.95, hydro 4.54 – 7.77 and wind 0.71-8.19.

being the £57.50/MWh CfD awarded to the Moray East and East Angelia wind farms (UK Government, 2017). Which are expected to be completed in 2022 and 2020 respectively.

In the next section we investigate the history of wind and potential of wind power in Scotland, with a focus on offshore generation.

1.3 Wind Energy in Scotland

There is a clear recent trend towards a 'greener' Scottish electricity sector with a greater share of capacity from renewables, for which both onshore and offshore wind playing a role. In this section we investigate the history and outlook for wind energy in Scotland, paying particular attention to offshore wind.

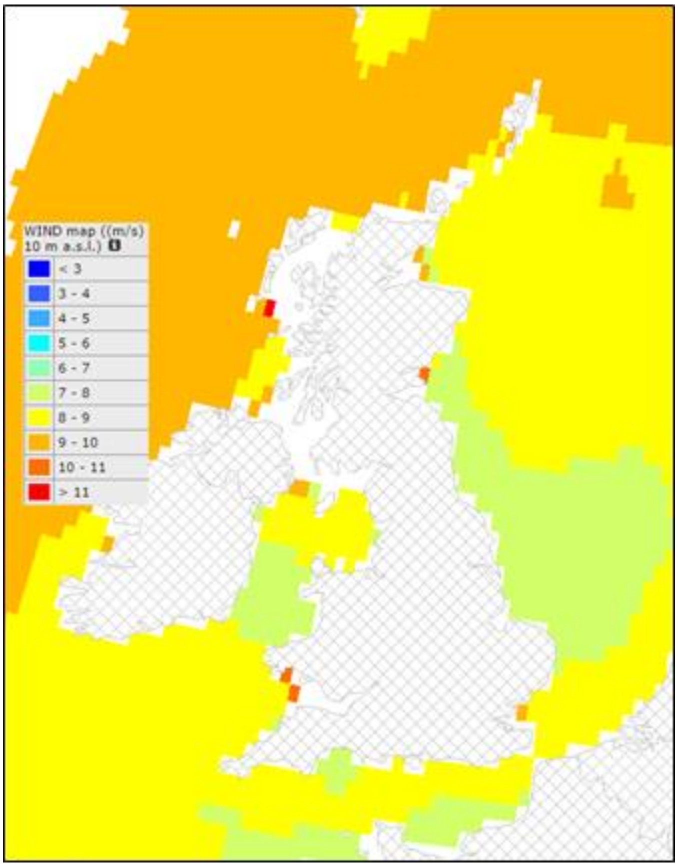
For centuries, through the use of a variety of techniques and devices, mankind has harnessed the energy from the wind – with windmills (used for grains and water pumping) being the most recognisable of the older devices. The roots of modern-day wind turbines however can be traced back to 1887 and the device developed by James Blyth (an engineer based at Anderson College – the predecessor to the University of Strathclyde). Although the principles of operation[13] of this device is completely different to current turbines, it is credited as being the first wind turbine converting the energy in the wind to electricity. Over the next century these devices matured into the recognisable three bladed turbines that we recognise today, with the 3-bladed HAWT being the most common design.

Scotland boasts some the best wind resource (both onshore and offshore) in the world, with an estimated 11.5GW of onshore capacity potential which could deliver 45TWh of electricity per year by 2025 (Snodin, 2001). With such a resource there has been a large number of onshore wind developments, as of October 2017 more than 281 onshore projects have been constructed amounting to 6.56GW with another 53 projects (1.67GW) under construction.

[13] The devices was a vertical axis wind turbine (VAWT) whereas nearly all wind turbines currently operational are horizontal axis wind turbines (HAWT).

The potential capacity for offshore is even greater than that for onshore. Scottish waters[14] posses 25% of all European resources (Scottish Government, 2011a) Figure 2.1 illustrates the wind speeds around the British Isles.

Figure 1.2: Annual average wind speeds UK.



Source: Orecca (2018)

From Figure 1.2 we find that the annual average wind speeds off the West coast and North of Scotland are generally higher than those for the rest of the British Isles. The power generated from a turbine is given by:

$$P = \frac{1}{2}\rho C_p A v^3 \qquad (1.1)$$

[14] Between 12-200 Nautical miles of the Scottish Coast.

Where: P is the power output; ρ air density; A rotor area; C_p power coefficient and v the wind speed. As the power is a function of the cube of wind speed, even a slight increase in the wind speed will have a significant increase in the power available.

While there has been significant increase in onshore wind developments, for offshore there has been a much slower development, with only one fully operational wind farm being built – Robin Rigg[15]. It was noted in Section 1.1 that the Scottish Government has an ambition to see up to 5GW of offshore capacity be installed by 2020. However the capacity of Robin Rigg. As of mid-2018, is only 174MW. There are several Scottish offshore wind farms at different stages of development (listed in Appendix 1A). This is in contrast with the rest of the UK which has seen a rapid rise in the number of offshore wind developments (outlined in Appendix 1B). So why, given Scotland's greater resource wind does offshore wind development lag behind the rest of the UK in 2018?

The first and most obvious reason for Scotland lagging behind the rest of the UK is cost of developments for projects. Scotland may have a much better resource but the environment which the wind farms will be built in are harsher (like the North Sea) which increase cost, especially O&M. To win a CfD contract a Scottish offshore wind farm competes in auctions with developments in the rest of the UK. This can be problematic as developers are less likely to invest in Scottish offshore wind if there are higher costs (if there is no reduction in O&M costs) – and thus lower profits relative to a development in the rest of the UK (if the wind speeds are similar). However, more recently there has been significant decrease in the cost of Scottish offshore wind with Moray East winning a CfD with a strike price of £57.50 MWh in 2017 (UK Government, 2017).

Another major stumbling block for the expansion of Scottish offshore wind energy has been opposition to developments. One notable instance of and offshore windfarm having opposition was the case launched by RSPB in 2015 against the Moray Firth and Neart Na Gaoithe developments. The RSPB claimed that these developments would have a detrimental effect on resident and migrating birds. This opposition led to a 'pause' in development of 3 years with

[15] There are other demonstrator projects such as Hywind and Beatrice.

the case only being resolved in November 2017, in favour of the Scottish Government. This had the effect of enabling development of these projects to continue.

As well as standard fixed offshore wind farms, a large potential for floating offshore wind has been identified for Scotland (FAI, 2017a). In 2017 the world's first floating offshore wind farm, the Hywind 30MW farm, was installed by Statoil in Scotland[16]. This technology is still in its infancy and as such there are many unknowns (i.e costs, local content) thus is not the focus of this PhD. It does however demonstrate the Scottish Governments commitment to develop the offshore wind resource.

This proposed expansion of offshore wind will have some economic impacts in Scotland, which is the focus of chapter 4 and 5. In the next section we investigate the links between the economy and the changing electricity network.

1.4 Scottish Energy policy and the economy

The previous sections of this chapter have outlined Scottish energy policy and the evolution of the electricity network and generation – with particular attention paid to offshore wind energy. In Section 1.1.1 the concept of the energy trilemma was introduced. Over recent years this trilemma has matured into the energy quadrilemma, with the addition of one other core dimension - economic development (Olabi, 2016). Economic development was seen as an afterthought in previous energy policy, but with the ever changing electricity system this is becoming an issue of political importance. The evolution of energy systems involves multiple large scale projects from which the public not only expect to produce secure 'greener' energy at a reasonable cost, but also the creation of an economic impacts e.g the creation of jobs.

As previously indicated the Scottish Government has recognised economic development as a key issue and feel that increasing renewable capacity has the potential to "reindustrialise Scotland" through the creation of many thousands of jobs. With economic developing coming

[16] Even though the turbines were installed in Scotland, the production of the components was carried out in Norway and Spain with the final turbines being towed across the North Sea.

to the forefront of energy policy there are several studies which quantify the impacts of green energy policy and renewables in Scotland.

While these studies have the same of objective of measuring economic development, each uses a different methodology and definitions on ‘economic development’. Innovas solutions (2011), using bottom-up survey data, estimate that in 2008/9 that the number of green jobs – including jobs supported through the supply chain - in Scotland was nearly 74,000. Whereas Scottish Renewables (2012) reports that there 11,136 direct jobs in 2011 by using surveys. Connolly et al (2016) used a hybrid methodology to measure the change in green jobs in Scotland between 2004 and 2012. In the paper it was found that up there was a clear increase in ‘green’ job employment from the mid-2000s till the economic down of 2008. The ‘green’ job numbers only start to increase again after 2010 indicating that there is a link to the overall economy.

These reports show one way of determining a link between economic development and green energy policy. However, differences in results show that there are complications in measurements with a large range of techniques and these papers only measure current impacts i.e there is little to stay about new developments.

Two standard frameworks which are used to measure economic impacts of new renewables/green energy projects and policies (see the literature reviews of Chapters 4 and 5) are IO and CGE. These frameworks differ from the above approaches as they are focused on the economic impacts (including employment) of future expenditure. As such, with our goal is to measure the economic impacts of increasing Scottish offshore wind capacity, we apply both these approaches.

1.5 Thesis structure and contributions

This thesis is split into two distinct parts: Part A (chapters 2 and 3) where we explore the electricity sector within the SNA framework and Part B (chapters 4 and 5) in which we model the economic impacts resulting from an increase Scottish offshore wind deployment. In this section we give an outline of each chapter along with their contributions.

As identified in the previous section, there is a clear link between the Scottish electricity sector and the economy. However, in standard economic accounts – including that for Scotland - the electricity sector treated as a single sector representing: generation, transmission, distribution and sales. These varying components of the electricity sector serve a range purposes and will interact with the economy in different ways. In Chapter 2 we extend the analysis of generation and consumption of electricity within the SNA framework by taking a satellite account approach. While there have been various application of satellite accounts in the literature (tourism, environmental, etc), in this chapter we develop the first (to our knowledge) Electricity Satellite Account (ElSA). The ElSA has been developed for Scotland using data for the year 2012. As this ElSA approach is the first of its kind we build on the elements of the Tourism Satellite Account (TSA) methodology and modify these for the electricity sector. Developing this ElSA provides a better understanding of the interactions between electricity generation and consumption and the economy.

As well as enabling a better understanding of the electricity sector, information from the Scottish ElSA can be used in the disaggregation of the electricity sector of IO tables, which is the focus of Chapter 3. In the existing literature there has been several examples in which the electricity sector within IO accounts has been disaggregated by generation technology (Allan et al, 2007; Cruz, 2002). Past disaggregation of the electricity sector has used top-down or survey methods. Also, previous disaggregations are typically based on the volume of generated electricity. One of the contributions of this chapter is that we apply a new hybrid method combining using both top-down and bottom-up data (from the Scottish ElSA). As described fully in the chapter, by using the information from the Scottish ElSA we are able to take the variation in electricity price by technology into account in the disaggregation of the electricity sector – the second contribution of Chapter 4.

Using the disaggregated IO table from Chapter 3, in Chapter 4 we calibrate and use an electricity disaggregated IO model to determine the potential economic impacts of an increase in Scottish offshore wind. For this purpose we explore the expected increase in offshore capacity, expenditure of offshore wind along with local content (detailed in the chapter) to build several simulation scenarios. IO modelling has been used previous to examine the impacts of single Scottish wind farm (Beatrice offshore windfarm Ltd, 2017; FAI, 2017b). The two fundamental contributions of Chapter 4 are to investigate: the cumulative effects of planned Scottish offshore wind developments and the impact of changes in local content on the economic impacts of purposed projects.

The IO model used in Chapter 4 is a special case of a CGE model with several assumptions most notably: fixed prices, a fully passive supply side and no substitution between inputs. Chapter 5 relaxes these assumption through the use of the AMOS CGE framework, with the particular framework used incorporating a disaggregated electricity sector. The same scenarios are run in this chapter as in Chapter 5 through the CGE model, which due to the relaxing of assumptions, allows for the impact on many more variables (than IO modelling) to be determined- such as wage rates and labour supply. To our knowledge this is the first attempt at modelling economic impacts of increasing Scottish offshore wind energy through the use of a CGE model.

Finally in Chapter 6 we give the main conclusion from each chapter of this thesis and outline potential future work.

As well as the contributions of each chapter, overall this thesis has a significance for Scottish policy makers. Detailed earlier in this chapter the Scottish government has a clear green energy policy with an emphasis on renewable electricity generation. To meet currently policy goals there is expected to be a large increase in offshore wind capacity at a large expenditure. In this thesis we explore the relationship between the electricity sector and the economy as well as the potential economic impacts of proposed Scottish offshore wind developments – which is important for policy makers to maintain the support of the public for such projects.

Part A – The electricity sector and the SNA framework

Chapter 1 observed that due to its large size and evolution over the last 20 years, the electricity sector in Scotland is of great importance to Scottish economy. With this importance and the constant evolution of the system there has been a volume of literature reconciling models of the economy with that of the wider electricity/energy system[17]. Economic models typically consider financial and monetary transactions, while energy/electricity models typically focus on the generation, transmission and consumption of energy. In this Part A we first present an approach to improve the representation of the electricity sector within the SNA framework (Chapter 2), then Chapter 3 outline how this can feed through to economic models.

[17] These are known as whole energy system models.

Chapter 2 – The development of an Electricity Satellite Account (ElSA) for Scotland

The rationale for this chapter stems from the idea that there is a fundamental challenge in the economic framework. In the economic System of National Accounts (SNAs) – the guidelines which govern the creation of economic– electricity activities are generally represented by a single aggregated sector, which incorporates generation, transmission, distribution and sales. This means the electricity sector is typically over aggregated creating challenges to any meaningful analysis of elements within the electricity system. The latest (2014) IO accounts for Scotland for instance provide an example of this (Scottish Government, 2018).

The aggregation of the different elements of the sector into one in the SNA raises a number of problems for meaningful economic analysis of the electricity sector. First, the various generation technologies in the electricity mix may each have different scales and linkages, all of which affect the economy in a distinct way: by aggregating into one sector these differences are 'lost'. For instance, the interconnectedness between the different generation technologies and the economy might be quite different depending on the (for example, materials, fuel and labour) inputs to each form of generation.

Secondly, different technologies will have quite distinct intra-day and seasonal variations in the pattern of generation. As a simple example, peaking plants (e.g pumped storage) will typically operate for a small number of hours at times of high prices, while baseload plants (coal, nuclear) will operate continuously. Identifying economic value of different generation technologies and within the electricity sector requires a more detailed analysis. This requires a detailed 'bottom-up' view on the nature of electricity generation by different technologies within the economy, not currently found within the SNA framework.

Third, the generation of electricity operates under different principles to those of the transmission, distribution and sales sectors which the standard SNA framework is not useful for understanding. Generation converts one type of energy to another, transmission transports electricity over long distances whereas distribution and sales supply the consumer with electricity. These sectors all interact with the economy in different ways but the SNA framework does not allow for this to be identified.

This problem of an economic sector not being well represented within the SNA is not unique, in fact in this chapter we argue that lessons from the analysis of satellite accounts can be usefully carried across to the analysis of electricity. We propose – to our knowledge – the first set of Electricity Satellite Accounts (ElSA). A satellite account provides:

> "a framework linked to the central accounts and which enables attention to be focussed on a certain field or aspect of economic and social life in the context of national account. (Common examples are satellite accounts for the environment, or tourism or unpaid household work)" (OECD, 2008).

Tourism was said to not have been well represented in economic accounts, which lead to the development of a tourism satellite account (TSA). These (satellite) accounts are independent accounts which give 'extra' information on the sector in focus but are linked to the SNA framework. The idea of an electricity (or energy) satellite account is not new, having first been identified by Teilet (1988).

The contribution of this chapter is to describe – for the first time – a methodology adapted from the literature on the creation of Tourism Satellite Accounts (TSAs) – to generate Electricity Satellite Accounts (sections 2.2-2.3) and then the creation of an ElSA for Scotland which reconciles economic accounts and energy balances for 2012 (2.4-2.6).

This chapter proceeds as follows: Section 2.1 gives an overview of satellite accounts, before Section 2.2 describes the creation and value of TSAs. Section 2.3 describes the development of the ElSA framework through the adaptation of TSAs. In the following three sections (2.4-2.6) the development of the first ElSA is described in detail with Sections 2.7 and 2.8 giving results and reproducibility of the tables respectively. Finishing up this chapter is Section 2.9 giving the conclusions from the ElSA development as well as reiterating the contributions of this chapter.

2.1 What are satellite accounts

The origins of national accounting can be traced back more than 300 years to 17th century England to William Petty and the first known attempt at a balance of the national economy (Stone, 1984). It is however Wassily Leontief who is credited (by many) as being the ‘founding father’ of modern economic accounting when he published his national accounts for the USA over 80 years ago (Leontief, 1936). With this paper he was able to identify the linkage between a 41 sector USA economy in 1919. Since then the same basic principles have been used extensively for the creation of national and regional economic accounts worldwide.

The Leontief accounts led to the creation of the SNA framework in 1947 by the UN. These are a set of internally recognised guidelines on developing economic accounts, which are also the basis for input-output modelling. These guidelines have been frequently updated, such as the major revision occurring in 1993 (Eurostat, 1993) and the last being in 2008. In the 1993 version the SNA framework was harmonised with other international standards to provide a framework standard and this is the base of what is used today. The 2008 update was relatively minor to address the issues due to changes in the economic environment[18].

According to ONS (2008) in order to be versatile and to maximise usefulness, the SNA must be generic in nature. This generic nature does however cause problems in that some aspects of the economy-of economic, political or social importance are not represented adequately enough in the SNA framework. To resolve this “satellite accounts” were developed, to extend the analysis of certain economic activities without causing the SNA framework to become overrun and unnecessary complicated. According to ONS (2008) there are 4 core questions which satellite accounts are set out to answer:

1. What is the total amount of resources devoted to the sector?
2. Who does the producing and with what means of production?

[18] These changes included updating the treatment of pensions, R&D and military expenditure.

3. Who finances the production in the sector?

4. What is the result of the expenditure and who benefits from it?

There are two broad categories of satellite accounts – internal and external (Harrison, 2006). Internal satellite accounts expanding further on the information found within the SNA framework (for examples TSAs). Whereas external satellite accounts (such as environmental) add material which are not part of the SNA framework.

In terms of current satellite accounts, TSAs are some of the most well developed and are the focus of Section 2.2. One other common type of satellite account is for research and development (R&D) expenditures. The reason for the development of these accounts is that R&D expenditures can be viewed as generating future income and, as such, R&D satellite accounts answer several key questions, otherwise unknown within the SNA framework including (Carson et al, 1994):

- How much is being spent on R&D?
- Who is performing and funding the R&D?
- How large is the capital stock of R&D and how does it compare with other capital within the economy?

Other than R&D satellite accounts, environmental satellite accounts are another which are well developed. These accounts contain a wide range of information related to the environment including: energy use; greenhouse gas emissions, water use, land use and government revenue from environmental taxes.

While there is accounting of energy use in the environmental satellite account framework, the focus is on the physical flows of energy. Also there is little consideration for the electricity, specifically generation and the interaction with the economy and different consumers. With the ElSA this is the primary focus (environmental being a secondary issue) which differentiates our ElSA methodology from the environmental satellite account.

2.2 Tourism Satellite Accounts (TSAs)

This section outlines: the purpose of TSAs; a brief history of the development of TSAs; the framework used to construct TSAs and the benefits obtained from these for analysing tourism activities. This is useful as it serves as a helpful comparator in the creation of ElSAs, which follows in Section 2.3 as this is the first methodology for an ElSA (to our knowledge). We use TSAs as they are the most widely used type of satellite account with an internally defined framework (Eurostat, 2008a).

2.2.1 Purpose of TSAs

The fundamental driving force behind the development of TSA was that tourism activities have specific characteristics that the SNA framework is ill-suited to capture. If we were to think of the activities of temporary residents (visitors), they are completely different to those of permanent residents. An obvious example of this is accommodation where a high percentage of temporary residents will spend money on hotels etc (which are tourism activities) whereas the spending for many permanent residents is on rent/mortgages.

Within the standard SNA framework there is no single economic activity to represent tourism, instead there tourism activities are carried out within several economic sectors. The developed TSAs allow for different types of tourism to be identified allowing for the estimations of key variables which are otherwise unknown within the SNA framework (Jones et al, 2005).

The key aggregates reported from the development of TSAs which are missing from an SNA framework (Eurostat, 2008a) are: internal tourism expenditure; internal tourism consumption; gross value added of tourism industries; tourism direct gross value added; and tourism direct gross domestic product. With the purpose of the TSA now explained, in the next section we look at the history and development of the framework.

2.2.2 History and development of TSAs

The TSA framework emerged in early 1983 (Smith and Wilton, 1997) when the World Tourism Organisation (WTO) stated that there was a need for an economic system with a "uniform and comprehensive means of measurement (of tourism) and comparison with other sectors of the economy" (Eurostat, 2008a). Over the next three decades there has been a great expansion on the development and use of these TSAs (Frenchtling, 1999) with Canada being noted as having the first fully developed TSA (Meis et al, 2004).

Initially, there was no standard method for the creation of TSAs (Smeral, 2006). Depending on the country or region, different measurements were taken, meaning that it was impossible to compare consistently the value of tourism activities across countries or update the TSAs over time.

An international standardized method was developed in the 2000s (Frechtling, 2010), with the latest framework (Eurostat, 2008a) detailing the information that should be included in a TSA[19]. Eurostat (2008a) notes that there are four principles to be followed when creating TSAs.

1. Base estimates on reliable statistical sources
2. Using statistical data that are produced on a continuing basis
3. Ensuring the comparability of data within the same country over time and across countries and other types of economic activity
4. Ensuring the internal consistency of all data used and comparability with other macroeconomic data (Eurostat, 2008a).

Since 2008 there have been many examples of the creation of TSA worldwide. Statistics New Zealand (2009) develop a tourism satellite account for New Zealand in 2009 with it being reported that there while there was an increase of tourism expenditure by 1.1% on the previous

[19] This framework is detailed later in this chapter

year the direct contribution of tourism decreased from 4.1% to 3.8%. Eurostat (2016) produces TSAs for 19 countries within Europe, although they are not split by country by product. The latest UK TSA (ONS, 2016) was for 2013 with the first 7 tables being developed according to the international standards.

2.3.3 TSA framework

To fully understand the framework of TSAs a definition of tourism must first be given. There are a number of variations, however a widely used definition is:

> "the activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes not related to the exercise of an activity remunerated from within the place visited" (Steeg, 2009)

Tourism can be thought as both a demand and supply-side phenomenon (Eurostat, 2008a). The demand side is the economic contribution of tourists through the consumption of goods and services, whereas the supply side is the activities which provides the goods and services used by tourist. For both demand and supply side, tourism products are typically identified. In the most recent UK tourism satellite account there are 12 tourism products ranging from accommodation services to sport and recreational activities (ONS , 2016)[20].

In the Eurostat (2008a) framework for TSAs there are a total of 10 tables, 7 of which are identified as "core tables"[21]. These tables gather information from a range of sources to reconciled in a set of internally consistent accounts, which are consistent with the SNA framework. The framework emphasis that as a minimum each TSA must include information on the supply and consumption of tourism (Tables 1 to 6) as well as information, for

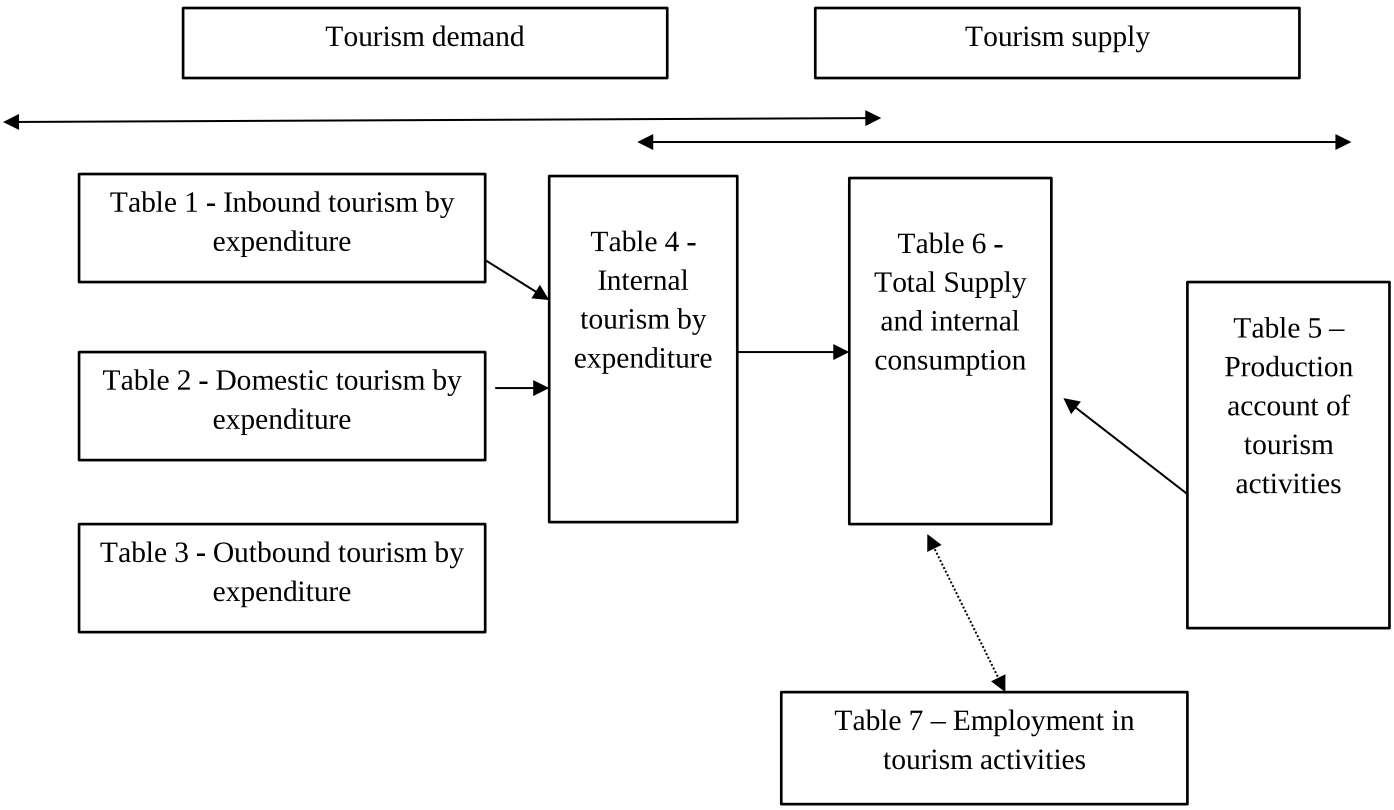
[20] Full list of products - Accommodation services for visitors, Food and beverage serving activities, Railway passenger transport services, Road passenger transport services, Water passenger transport services, Air passenger transport services, Transport equipment rental services, Travel agencies and other reservation services, Cultural activities, Sport and recreation activities, Exhibitions & Conferences etc. and Other consumption products.

[21] There is some inconsistently on whether there are 7 or 8 core tables. As there are many published accounts (e.g ONS (2016)) which publish with 7 tables we use this as the core number.

employment policy, on the employment in tourism activities (Table 7). The information contained within Tables 1-6 are given in monetary value with the first 5 tables represented in basic prices and Table 6 in purchaser prices[22].

Tables 8 (tourism gross capital fixed formation of tourism industries and other industries) and 9 (tourism collective consumption, by products and levels of government) are not considered to be part of the core tables. As this chapter will focus on adapting the TSA framework for the electricity sector the focus is on the first 7 tables. The high-level schematic below shows the linkages between these first 7 tables:

Figure 2.1: Schematic of TSAs framework.



Source: Adapted from Frechtling (2010)

[22] Basic price is the price received by the producer excluding taxes whereas the purchaser's price is the price paid by the purchasers which includes taxes and trade margins.

The Tables 1 to 4 are focused on the demand of tourism within the region; further schematics for each are given below with explanation given.

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Table 2.1: Schematic of Table 1 of TSA framework.

Products	**Inbound tourism expenditure**		
	Tourists (Overnight) (T1.1)	Excursionist (T1.2)	Total visitors (T1.3=T1.1+T1.2)
Accommodation services for visitors (TA1)			
Food and beverage services (TA2)			
Railway passenger services (TA3)			
Road passenger services (TA4)			
Water passenger services (TA5)			
Air passenger services (TA6)			
Transport equipment rental services (A7)			
Travel agents and other reservation services (TA8)			
Cultural services (TA9)			
Sports and recreational services (TA10)			
Country-specific tourism characteristic goods (TA11)			
Country-specific tourism characteristic goods (TA12)			
Other consumption products (TB1)			
Valuables (TC1)			

Source: (Eurostat, 2008a)

Table 1 represents the tourism expenditure for inbound tourism – the activities of non-resident visitors within the country of reference (Eurostat, 2008a). From Table 1 of the TSA there are 12 (TA1-TA12) tourism consumption products, these are standardized products which should appear in TSAs worldwide. Table 1 of the TSA illustrates that the distinction between overnight (T1.1) and same day (T1.2) is made, with both summing to give total visitor expenditure (T1.3). To develop these tables, data is needed on inbound tourism usually gathered through the use of surveys. For the UK TSA the International Passenger Survey (IPS) is used along with ONS Consumer Trends and Input-Output tables are used for the creation of Table 1 (ONS, 2016).

Below a schematic of Table 2 of the TSA framework is given.

Table 2.2: Schematic of Table 2 of TSA framework.

Products	**Domestic tourism expenditure**		
	Domestic trips (T2.1)	Outbound trips (T2.2)	Total Domestic (T2.3=T2.2+T2.3)
Tourism consumption products (TA1-T12)			
Other consumption products (TB1)			
Valuables (TC1)			

Source: (Eurostat, 2008a)

Again, Table 2 of the TSA is broken down into 12 consumption products (TA1-A12). Domestic tourism is defined as the activities of a resident visitor within the country of reference. In Table 2 of the TSA framework there are two types of domestic tourism activities, domestic trips (T2.1) where expenditure made within the country of reference on domestic tourism activities and outbound trips (T2.2) where the expenditure being made within the country is part of an outbound trip[23].

[23] An example of this type of expenditure is travel agents fees.

As with the tourism in the TSAs first table, both domestic and outbound tourism may be separated into tourists and excursionists. For Table 2 of the UK TSA the data sources used are: IPS – for the estimation of outbound travel fairs; Great Britain Tourism Survey (GBTS) – Information of domestic overnight tourism; Great Britain Day Visit Survey (GB-DVS) – domestic day trip survey and the Northern Ireland Continuous Household Survey as Northern Ireland residents are not interviewed for the GBTS or GB-DVS (UKTSA). Table 2.3 gives a schematic for Table 3 of the TSA framework.

Table 2.3: Schematic of Table 3 of TSA framework.

Products	**Outbound tourism expenditure**		
	Tourists (Overnight) (T3.1)	Excursionist (T3.2)	Total visitors (T3.3=T3.1+T3.2)
Tourism consumption products (TA1-12)			
Other consumption products (TB1)			
Valuables (TC1)			

Source: (Eurostat, 2008a)

Table 3 of the TSA framework is a mirror image of Table 1 with the difference being the focus is on outbound tourism, i.e the activities of residents outside the region of reference. Similar to Table 1 of the TSA, Table 3 is populated using data from the IPS and Input-Output tables. TSA Table 4 combines the information for Tables 1 and 3 to give overall internal tourism consumption found in Table 2.4.

Table 2.4: Schematic of Table 4 of TSA framework.

Products	**Domestic tourism expenditure**			Other components of tourism Consumption (T4.2)	Internal tourism consumption (T4.3)
	Inbound tourism expenditure (T1.3)	Domestic tourism expenditure (T2.3)	Internal tourism expenditure (T4.1=T1.3+2.3)		
Tourism consumption products (TA1-12)					
Other consumption products (TB1)					
Valuables (TC1)					

Source: (Eurostat, 2008a)

In this Table 4 of the TSA, total internal tourism expenditure (T4.3) is a combination of the total inbound and domestic tourism from Tables 1 and 2 of the TSA respectively. T4.2 are other components of tourism consumption not recognised by the other tables which can be split into three main categories: Services associated with vacation accommodation on own account; Tourism social transfers in kind (except refunds) or other imputed consumption.

As with the demand side of the TSA, each table in the supply side (Tables 5,6,7) is displayed by a schematic and explanation given, beginning with Table 5 below:

Table 2.5: Schematic of Table 5 of TSA.

Products	**Tourism Industries**				Other industries (T5.14)	Output of domestic producers (T5.15=T5.13+T5.14)
	Accommodation for visitors (T5.1)	……..	Country specific tourism industries (T5.12)	Total (T5.13)		
Tourism consumption products (TA1- 12, TB1)						
Non-consumption products (TD1)						
Total output (at basic price) (TE1)						
Total gross value added (TF1)						

Source: (Eurostat, 2008a)

Table 5 provides a representation of the production of tourism activities at basic prices in a product (rows) by industry (columns) representation. From above, the number of tourism industries matches the products with there being twelve of each, although this does not need to always be the case as will be explained later in the chapter. This table gives an overview of the full economy thus non-tourism (TB1) products are included. TF1 represent the value added which can be separated into the separate components (compensation of employees, gross mixed income, taxes less products and gross operating surplus) if possible. The information for the development of this table comes from the SNA framework. In Table 2.6 the schematic for the Table 6 of the TSA framework is given.

Table 2.6: Schematic of Table 6 of TSA.

Products	Tourism industries											
	Accommodation for visitors (T5.1)	….	Country specific tourism industries (T5.12)	Total (T5.13)	Other industries (T5.14)	Output of domestic producers (at basic prices) (T5.15)	Imports (T6.1)	Taxes less subsidies (T6.2)	Trade and transport margins (T6.3)	Domestic supply (T6.3)=(T5.15 + T6.1+T6.2+ T6.3)	Internal tourism consumption (T4.3)	Tourism ratio (T6.5=T4.3/ T6.4*100)
Tourism consumption products (TA1-12,B1)												
Non-consumption products (TD1)												
Total output (at basic price) (TE1)												
Total gross value added (TF1)												

Source: (Eurostat, 2008a)

Table 6 of the TSA framework contains information on both the demand side and supply side of tourism. The first half of Table 6 is created using the information directly from Table 5 with products and outputs at basic price. To convert these prices to purchaser's price information must be gather on the imports, taxes less subsidies and trade and transport margins which are displayed in columns T6.1, T6.2 and T6.3. Also included in this Table is the internal tourism consumption (T4.3) which is used to calculate tourism ratios (T6.5). The final table presented is Table 7 in Table 2.7.

Table 2.7: Schematic of Table 7 of TSA.

Tourism Industries	Number of establishment	Number of jobs by status in employment					
		Employees			Self Employed		
		Male (T7.1)	Female (T7.2)	Total (T7.3)= (T7.1+T7.2)	Male (T7.4)	Female (T7.5)	Total (T7.)= T7.4+T7.5)
Accommodation for visitors (T5.1)							
….							
Country specific tourism industries (T5.12)							

Source: (Eurostat, 2008)

Unlike the other 7 tables of the TSA framework the layout of Table 7 is generic in nature which can vary between accounts, as it displays as much information as possible on tourism employment within the region of focus. The information found within this table may be aggregated depending on the information available. In the schematic Table 7 above, employment is broken down by the tourism industries found in Tables 5 and 6 and further by type of employment and sex. For Table 7 of the UK TSA information is gathered from the

Annual Business Survey (ABS); Annual Survey of Hours and Earnings and Business Register and Employment Survey.

As noted in this section, in this chapter we use 7 of the “core” tables of the TSA in the development of ElSA. The first four of these tables give the tourism consumption by tourist type (inbound, domestic, outbound) with Table 5 being a production account related to the SNA and supply of tourism. Table 6 reconciles internal tourism with domestic supply and Table 7 gives employment detail for the tourism industries. These core tables allow for a rounded picture of the diverse impacts of tourists in the economy with much greater resolution than one would get from the SNA. The lack of a single tourism sector in the SNA makes determining the economic role of tourism activities using the standard SNA framework impossible.

According to Heerschap et al (2005) the development of TSAs can be a pain-staking process with a large amount of time taken ensuring that the data sources are in line with the principles outlined above. Also, they suggest there is the potential for confidentiality issues to in the development of the tables TSA with the data used to disaggregate parts of tourism may be commercially sensitive which may be the same in the development of ElSA, explained later.

With the purpose, history, development and framework of TSA outlined the next section of this thesis investigates the transfer of properties of a TSA in the development of an ElSA. We however, suggests that there are clear benefits of TSAs.

2.3 Transfer from Tourism to Electricity

In the previous section the TSA framework, a robust and internationally recognised framework for reporting on activities of the tourism sector, was presented. The TSA approach allows for a more detailed examination of the role(s) played by tourism in an economy.

In this section, we outline the development of the TSA so that it can adapted for the creation of an ElSA to better represent the electricity sector within the SNA. The preceding section helps to inform the practical steps in gathering and reconciling data which permits the construction of ElSA. We report that this is the first – to our knowledge – empirical creation of a satellite account for an electricity system.

While we are using the principles of the TSA to create an ElSA, there is a slight difference in the two accounts. There is no single tourism economic sectors identified in the SNA for producing tourism activities or consuming tourism products, rather in there are tourism components with a wide range of sectors. TSAs gather information on this tourism sectors.

There is however an electricity sector within the SNA but contains this a wide range of components - generation, transmission, distribution and sales. These components all serve a separate purpose and interact with the economy in a different manners. Unlike the TSA were the purpose is to report on the tourism found within several sectors, the purpose of the ElSA is to increase the coverage of one component (generation) of the electricity sector within the SNA.

To determine if an adaption of the TSA framework was suitable for the electricity sector we must answer the question: What are the similarities between electricity and tourism?

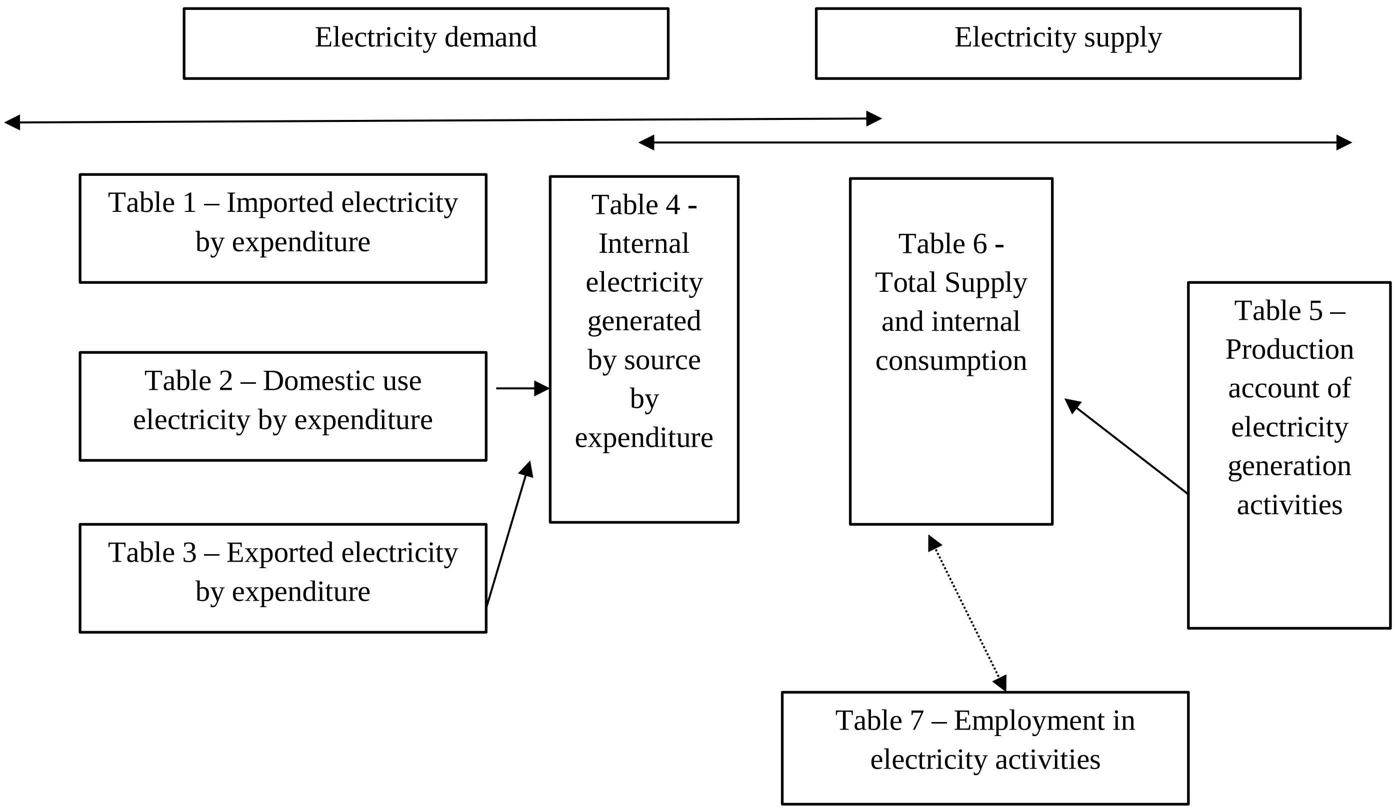
At first glance, it may appear that there are few similarities between electricity and tourism making it difficult to transfer the properties from the TSA framework to an ElSA. However, there are similarities and areas of crossover.

As mentioned earlier, there are many different types of tourism products (e.g. food and beverages) which are all different but make up a final tourism consumption product. We can think of electricity in the same manner, useable electricity is the final consumption product which can be produced at different times in a variety of different ways by different generation technologies (e.g. different electricity products).

Also investigating Figure 2.1 we find that there are three types of tourism tables (inbound, domestic, and outbound) which constitute a 'flow' of expenditures. Electricity is also a flow, which can be imported, used domestically or exported.

These two fundamental similarities mean that the adapting the TSAs framework is be useful improving the coverage of the for the electricity sector in the SNA. Figure 2.2 below demonstrates the ElSA framework, and might be compared to Figure 2.1 (the overall TSA framework).

Figure 2.2: Schematic of ElSA framework.



Source: Author's analysis

If this is compared to the TSA framework found in Figure 2.1, we can see that the framework is near identical. There is an electricity generation part with tables for imports, domestic use and exports[24] which mirrors the tourism demand section of Figure 2.1. Table 5 again is part of the supply side with Table 6 being the main table combining the information. In a similar manner to Section 2.2.3 the outline and explanation of each table of the ElSA is given below, beginning with Table 1[25].

[24] We note that in the TSA Table 1 physical tourist come from abroad thus the expenditure arrives. ElSA Table 1 physical electricity arrives but expenditure is being sent to generators abroad. This is a slight difference which we detail further in the explanation of Table 2.11

[25] This is only the outline of the framework, sections 2.5 and 2.6 deal with the development of the first ElSA

The tables found in this section are only illustrative to give a detail on the adaptation of the TSAs to the electricity sector. Found in later sections are details on the data and processes used to populate the tables, as well as the analysis that these tables permit.

Table 2.8: Schematic of Table 1 of ELSA framework.

Products	**Imported electricity expenditure**			
	Electrical consumer 1 $_{(E1.1)}$	….	Electrical consumer n $_{(E1.n)}$	Total Imported (E1.(n+1)= ∑E1-E1.n)
Generation type 1 $_{(EA1)}$				
…				
Generation type n $_{(EAn)}$				

Source: Author's analysis

Table 1 of the ElSA represents the electricity generated abroad but consumed within the region of focus (Scotland). Similar to the TSA tables there are different products, which in the case of electricity are the generation technologies. Unlike the TSA framework though, where there are 12 well defined products, there is the possibility for there to be ElSA products to vary depending on the region of focus. Ideally there would be every type of generation included, but with current information this is may not be feasible[26].

In the TSA there were two well defined types of consumers (Tourists and Excursionists) whereas in the ElSA – in a similar manner to the products – the numbers of different types of consumers is dependent on the information available. There are many consumers of electricity

[26] In the 2012 Scottish ElSA which we develop here there are 7 electricity products – coal, gas, nuclear, flow hydro, pumped hydro, wind and other.

within the economy and ideally the number of consumer types within the SNA framework would match the final demand sectors within the SNA accounts.

The information to populate the tables used a variety of sources and models. This is the focus of Sections 2.5 and 2.6. Table 2 of the ElSA framework can be found below.

Table 2.9: Schematic of Table 2 of ELSA framework.

Products	**Domestic use electricity expenditure**			
	Electrical consumer 1 (E2.1)	….	Electrical consumer n (2.1)	Total domestic (E2.(n+1)= ∑E2.1-E2.n)
Generation type 1 (EA1)				
….				
Generation type n (EAn)				

Source: Author's analysis

This table is used to display the expenditure by consumers on electricity generated and consumed within the country of focus, domestic use. In Table 2 of the ElSA framework, as with Table 1, there are both products and consumers of electricity. Ideally the products of both these tables should match, however this may not be possible as it is likely to be more difficult to find information on the generation outside the region of focus. All the consumers in Table 1 of the ElSA should be found in Table 2 along with some other 'domestic only' consumers such as losses[27].

[27] Losses are inevitable in an electrical system as during transportation there is a conversion to heat, these losses need to be identified in the ElSA in Table 2. Other domestic only consumers are generators own-use (to operate electrical generators will also consumed electricity) and pumped storage – explained later in this chapter.

Like Table 1, Table 2 of the Scottish ElSA was populated using information from Sections 2.5 and 2.6. Table 3 of the ElSA framework is found below.

Table 2.10: Schematic of Table 3 of ELSA framework

Products	**Exported electricity expenditure**			
	Exported region 1 (E3.1)	….	Exported region n (E3.n)	Total exports (E3.(n+1)= ∑E3.1-E3.n)
Generation type 1 (EA1)				
….				
Generation type n (EAn)				

Source: Author's analysis

Table 3 of the ElSA is the expenditure of electricity generated in the region of focus but consumed elsewhere. The table is near identical to the domestic use, with the same number of generation products – as the same potential range of generators are used. However instead of the consumers being domestic they are separated depending on the region where the electricity is exported to.

Again Sections 2.5 and 2.6 explain how the data was generated to fill this table. Table 4 of the ElSA framework is found below:

Table 2.11: Schematic of Table 4 of ELSA framework

Products	**Domestic generated expenditure**		
	Total Domestic use (E2.16)	Total export (E3.3)	Total domestic generated (E4.1=E2.1+E3.3)
Generation type 1 (EA1)			
….			
Generation type n (EAn)			

Source: Author's analysis

In the TSA framework Table 4 was a combination of Tables 1 and 2 to give an overview of total tourism expenditure within the region of focus. This is the case as inbound and domestic tourism are of importance for the regional economy. Whereas through adapting this framework for electricity it is Tables 2 and 3 which are combined to generate Table 4 of the ElSA framework. The reason for this is that even though the electricity is physically being used out with the region, it is the Scottish generators that gain the income. Again similar to TSA framework, Table 5 of the ElSA is a production account found in Table 2.12.

Table 2.12: Schematic of Table 5 of ELSA framework.

Products	**Electricity generation production account**					
	Generation industry 1 (E5.1)	….	Generation industry n (E5.n)	Total (E.(n+1)=∑E5.1-(E5.n+1))	Other Industries (E5.(n+2)	Output of domestic producers (E5.(n+3)= E5.(n+1)+5E(n+2)
Generation type 1 (EA1)						
….						
Generation type n(EAn)						
Non generation products (EB)						
Value added (EE)						

Source: Author's analysis

In the same manner in which Table 5 of the TSA framework is a production account for the supply of tourism, Table 5 of the ElSA framework is a production account for the electricity generation sector. This table contains information on the industries in which the generation products (electricity) is being used. As this is an electricity account the focus of this table is focused on the relationships between the electricity generation products and industries. Along with information on the generation products and industries, this production account contains the aggregated information from the other products (EB) and industries (E5/(n+2)) of the economy as well as industrial value added (EE).

Mentioned in Section 2.2.3 the number of products and industries within a production account do not need to match. In a similar fashion to Table 6 of the TSA framework the following table in the ElSA brings together the key information from the first 5 tables.

Table 2.13: Schematic of Table 6 of ELSA framework.

Products	**Supply of Scottish Electricity**					
	Output of producers (E5.(n+3))	Exports (E3.3)	Taxes / Less Subs (E6.1)	Domestically (basic prices) (E4.2)	Domestic generated (purchasers price) (E6.2=E4.2+E6.1)	Domestic consumption
Generation type 1 (EA1)						
….						
Generation type n(EAn)						
Electricity non generation (EB1)						
Other non-electricity (EC1)						
Total output (ED1)						
Value added (EE1-EEn)						

Source: Author's analysis

Similar to Table 6 of the TSA, Table 6 of the ElSA framework contains information on both the supply side and demand side of the electricity sector. Output of producers is directly from the production account of Table 5 with the exports from Table 3, instead of imports found in the TSA framework. This occurs as, similar to Table 4, the focus is on the electricity focused within the region.

E6.1 from the table above is the information on taxes and subsidies. In the SNA framework these taxes and subsidies are separate but as there is a range of these mechanisms for the electricity sector it is advantageous for these to be separated by technology. Also by including these taxes and subsidies the output of the generators can be converted from basic to purchaser's price. Finally in Table 6 detail is given on the demand side of electricity with the overall domestic consumption (taken from the domestic consumption in Tables 2/4).

The final table of the ElSA framework has a focus on employment found below.

Table 2.14: Schematic of table 7 of ELSA framework

Electricity industry	Full time employment	Part time employment	Total employment

Source: Author's analysis

Unlike the other 6 tables within the ElSA framework there is some flexibility in the information contained within the employment table. This is highly dependent on the information available – as well as confidentiality – but the minimum required would be the total employment in different element of the electricity sector, including the generation technologies.

In this section the adaption of the TSA framework for electricity has been explained with an outline of each of the tables given. Proceeding this section is information on how the first ElSA (for Scotland in 2012) was developed.

As with the TSA framework there are several key aggregates which development of the ElSA gives including: domestic electricity expenditure (ElSA Table 2); exported electricity expenditure (ElSA Table 4); taxes and subsidies by technology (ElSA Table 6) and GVA of electricity generation (ElSA Table 5).

2.4 Possibility of an ElSA for Scotland

Scotland was an ideal candidate for the development of the first ElSA for a number of reasons. The unique political and geographical position of Scotland in the UK aids in the development of the ElSA. Geographically, Scotland is isolated in North West of Europe with only two electrical connections to other 'countries', England and Northern Ireland. This made aspects of the data requirements (e.g. imports and exports) more straightforward than regions which have more connections with a broader range of other regions/countries. As England and Northern Ireland are regions of the UK, the same data sources can be used. Also, the electrical network in the UK is rather modern with a high level of monitoring and parts of this are available on the public domain. Finally Scotland is well served with economic data with, for example, official IO tables being published annually by the Scottish Government.

In Chapter 1 we see that there is a clear policy goal of 'greener' Scotland with a large part of the focus being on renewable electricity. With this increased focus on the electrical network, it was felt that an ElSA would be idea for Scotland for not only determining the value of the sector to the economy but also for use in economic modelling for the use of impacts studies of new technologies (Chapter 3-5).

In a sense as Scotland is part of the UK the ElSA developed can be seen as regional account instead of national. Jones and Munday (2010) indicate that regional TSAs are beneficial as tourism spending patterns are highly dependent on location thus a national account TSA might poorly represent the specific tourism activities of a region. The same can be said for an ElSA, no two electrical systems will be the same thus a more specific ElSA is more advantageous for regional analysis.

2.5 Development of electrical supply demand match model

As Figure 2.2 the ElSA schematic sets out, Tables 1 to 4 framework denote in turn:

- Expenditure on imports of electricity produced outside Scotland.
- Domestically produced electricity consumed in Scotland.
- Electricity produced in Scotland and consumed by agents outside of Scotland.
- Total domestically produced electricity

In order to understand the requirements of each table – specifically, the expenditure by different consumer types (e.g. industry/households) on different types of electricity generation (products) - one must have information on the time paths of electricity supply by technology, and electricity demand by consumer type. This was achieved through the development of a half-hourly supply/demand matching model, which is the focus of this section. Our starting point for this is to get information on electricity generation, by generation station, for each time-step to characterise Scottish electricity supply, the focus of Section 2.5.1. Using this half-hour data we can then aggregate to match with the annual economic data.

2.5.1 Supply of electricity (Generation)

Section 2.4 established that the products within ElSA are the generation technologies, with their output (in MWh converted to pounds) is of importance energy information was obtained from both publically available data (Elexon) and models to produce the necessary electrical generation elements for the ElSA framework. Section 2.6 then describes how this data was then used to populate the ElSA account for Scotland in 2012.

2.5.1.1 Elexon data on generation of electricity

The main source of data for the development of the half-hourly generation was the Elexon portal[28]. This is an open source database containing information on the GB electricity network with the information obtained directly from national grid. In this portal there is a range of variables – including trades and balancing[29]. For the purposes of the ElSA, it is the identified physical (kWh) output by individual generator, monitored by National Grid, which is of importance. The dataset that we use for the development of the Scottish ElSA relates to the balance mechanism. It is well known that electricity cannot currently be (economically) stored in large quantities and as such - on any electrical network - it is imperative that at all times supply must meet demand[30]. The responsibility of ensuring this balance of supply and meets demand at all times in the UK falls on National Grid (NG), and this balance is achieved by NG's use of the GB balance mechanism (BM) (National Audit Office, 2014).

The BM splits a day into 48 half hourly periods where suppliers must estimate the potential demand for that period and enter into an agreement with generators to supply the required electricity, which is known as a final physical notification (FPN)[31]. In each half hourly settlement period the balance mechanism has two main objectives. Firstly, to ensure that each of these FPN contracts are adhered to. Secondly, to ensure that the transmission system is operating in a safe manner by instructing operators to vary output depending on the supply/demand match (Elexon, 2013a). In situations where supply needs to adjust, dispatchable power plants (e.g. coal, gas, pumped storage) are used to carry out the balance as it usually not economically viable[32] to reduce wind or nuclear output.

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[28] https://www.elexonportal.co.uk

[29] Trade reports contains information on the wholesale markets trade. Balancing reports provide the changes made to generation to meet the supply needs.

[30] If the supply does not meet demand there will be a divergence from the national frequency of the system, potentially causing problems to devices or even blackout. The UK natural frequency is set at 50Hz.

[31] These FPNs are agreed an hour before the beginning of the settlement period.

[32] Wind can only generate then the resource is available thus to maximise economic output must generate needs to run as much as possible. Whereas, with the principle of operation nuclear power runs and near full power most of the time.

Instead of giving information on the exact metered output by each generator in MWh, two variables within the Elexon databases are combined to determine the output of each generator. The two variables are the FPN and bid offer acceptance (BOA). As mentioned, above the FPN is the contract submitted an hour before the settlement period (gate closure) determining how much electricity the generator, expect to output. BOAs are the changes in output that National Grid instructed to each of the generators. Thus by combining (subtracting BOA from FPN) the information from both the FPN (what they said they would generate) and BOAs (changes they were requested to make) we can obtain the actual amount of each generators output in each time period. (Elexon, 2013b).

There are some other slight data format considerations which need to be taken into account when using the Elexon data. These occur mainly due to the conversion of financial data to calendar year, and the filtering to Scottish generators. This was done based on the identification by postcode of Scottish generation facilities[33].

In Section 2.2 we identified four main principles which had to be taken into account. The first two points indicate that the satellite account must be created using reliable data, and which is provided on a consistent basis. Both are true for the Elexon portal as the information comes directly from National Grid and is constantly updated.

There are two types of connected electricity generation capacity in Scotland. Transmission connected – typically larger generators – and those connected to the distribution level, typically smaller projects. A problem with the Elexon portal is that the focus is on the larger transmission wind generators, it does not cover smaller wind farms connected to the distribution network. As such a wind model (Section 2.5.1.2) had to be created to determine total half-hourly output- this is detailed in Appendix 2A.

Elexon was not the only data that was used for the development of the supply/demand match model. Data from the Department of Business, Energy and Industrial strategy (BEIS) publications (BEIS, 2016b) was also used. These data were used in the calculations of some half-hourly parameters of the electricity sector for example, losses. As with the Elexon portal

[33] The raw data is from April-2011 to April 2013 and includes all the UK generating facilities.

these data meets the criteria from Section 2.2 as it is from a reputable source, and is published at least annually.

With the use of the Elexon data, the electrical output of most generators with Scotland at each half-hour time-step is known. Using this and the wind model from Appendix 2A, half-hourly output by generation for Scotland is known by plant.

2.5.2 Demand for electricity

With the half-hourly generation by technology known, for the supply-demand match model, we need the half-hourly Scottish demand by sector. Unfortunately for Scotland this type of information is not available. The current data available is: half-hourly GB consumption (Elexon), Half-hourly England and Wales consumption (Elexon), Scottish annual overall consumption and Scottish annual demand by 12 economic sectors (From BEIS). These figures are estimates using the frequency response system[34] as without the full implementation of smart meters (Depru et al, 2011) there is no way to precisely calculate the electricity demand by sector. As the information on half hourly Scottish sectoral electricity consumption is not available a detailed demand model was used for these calculations. For the purpose of reproducibility and transparency, the data necessary were obtained from publically available data sources. The following sections detail the model developed to estimate Scottish half-hour electricity demand by sector.

2.5.2.1 Previous electricity demand models

In recent years there have been several attempts to model electricity demand in several countries worldwide (including the UK). In both the engineering and economic literature we find that there have been attempts to use past consumption data as the input for forecasting models. These forecast models can be based on the principles of linear regression and can be

[34] Using the principle that when electricity generation is greater than demand then the frequency of the system is greater than 50hz and when there is more demand that there is supply the frequency drops below 50Hz

used for overall demand (e.g Dilaver 2012) or more commonly in the economic literature for long or short term electricity price forecasting (e.g Skantze et al, 2000: Coulon and Howison, 2009). What is wanted for the creation of ElSA is demand for past period (rather than forecasting) and as such the techniques identified above cannot be applied, also they are focused on demand in the overall grid instead of individual sectors.

Unlike the economic literature, in some of the engineering literature the focus has moved from forecasting into more detailed modelling of previous electricity demand. For example (Reichmuth, 2008) and Farinaccio et al (1999) focus on disaggregating overall household consumption into final use. This is not directly useful for our model but gives an idea of different methods in which electricity demand can be split. In these papers, total household demand is known and the authors split household final use of electricity by components (such as refrigeration, heating etc) using demand profiles. The process of disaggregating one electricity component into other final uses is what is to be achieved in the ElSA demand model, albeit the final uses are economic sectors instead of individual appliances.

The paper which is of most relevance to the creation of the ElSA demand model is Hesmondhalg (2012). In that paper, the author develops demand profiles for three sectors (household, industrial and commercial) and uses these along with BEIS data to develop a half-hourly demand from quarterly and yearly data. There are two limitations of Hesmondhalg (2012) in terms of our work: first, its focus on the GB as a whole, rather than Scotland; and second, that electricity demand would ideally be disaggregated further than the three sectors presented to provide details on the way in which electricity is used in economic activities.

2.5.2.2 Calculation of Scottish half-hourly demand

The first stage of the demand side of the model is to estimate the half-hourly electricity demand for Scotland for 2012. BEIS only publish overall yearly and quarterly figures however using the information from Elexon we can estimate Scottish half-hourly demand. The Elexon data contains half-hourly demand on GB demand and England/Wales demand. In the absence of half hourly Scottish demand data, we used GB demand to estimate Scottish half-hourly demand using:

$$Scottish\ demand\ (t) = GB\ electricity\ demand\ (t) - (England + Wales\ electricity\ demand)\ (t) \qquad (2.1)$$

As the GB grid only consists of Scotland, England and Wales seems a reasonable estimation.

2.5.2.3 Half hour demand by sector

With the half-hour overall electricity demand known we need the demand by sector. To apply a method similar to that of Hesmondhalg (2012) demand profiles for different sectors are needed. Typical demand profiles give the normalised output for a sector for a day in half-hourly time steps and can be created in one of two ways. The first is to physically measure the electrical consumption of different building types found within a sector (with differing purpose, size, occupancy etc) over an extended period of time, similar to the work by Reichmuth (2008). This will give accurate data but can be problematic as to take into account seasonal variations, measurement would need to span at least a year and each building type used in each sector would have to be measured, increasing the cost and data need significantly. To overcome these problems it has become common practice to model the electrical consumption of buildings using generic sectoral types (Clarke et al, 2011).

Here we use 12 demand profiles to model the final electricity demand for 12 sectors. There sectors were domestic, industry, offices, communication, education, government, health, hotel, other, retail, sport and warehouse. Ideally the demand profiles would be disaggregated further (such as types of industry) but with data constraints this is not possible[35], but may be in the future. For the domestic and industrial sectors the profiles where taken from the Elexon portal which use real data and are highly accurate. For the other 10 sectors, profiles were taken from Ofgem (2012) which again are generated using real measured data.

[35] BEIS overall demand is only split by these 12 figures and these were the only generic profiles found.

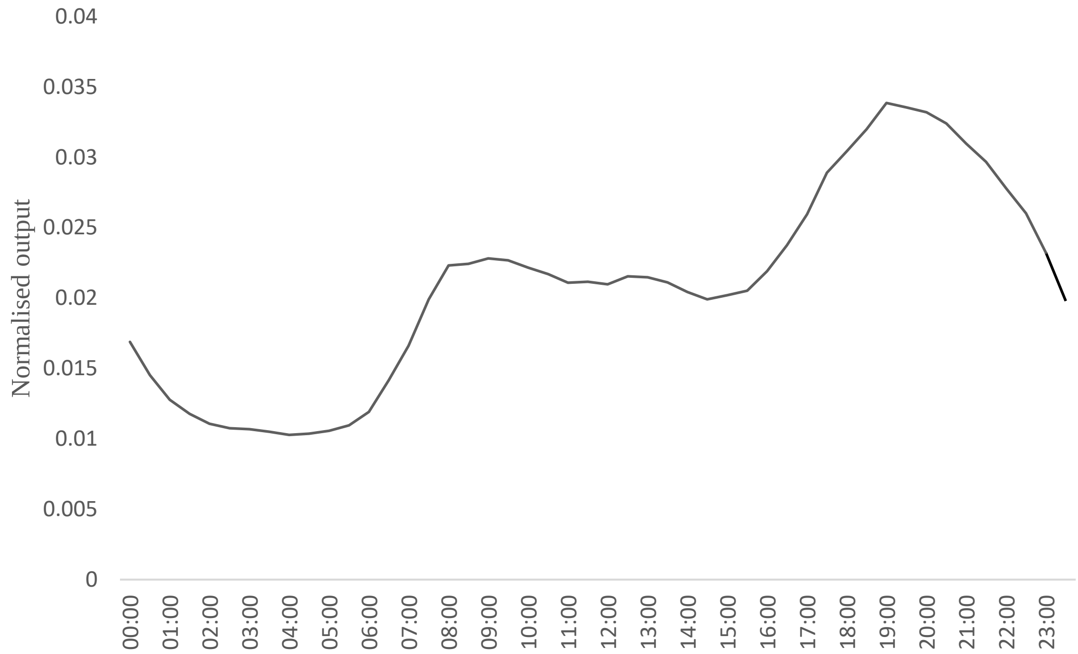
When using the generic demand profiles it must be emphasised that for them to be created a large number of buildings, with varying attributes (like size, occupancy, etc), of the same sector had to be measured and the generic demand profile is the aggregated value of these measurements. This means of course that if you were to look at the demand profile of an exact building in a given sector it may look completely different from the generic profile for that sector. But as we are looking at sectors in general these average profiles work well.

To represent the different usage of buildings throughout the week, different profiles are given for weekdays and weekends from Ofgem which the Elexon portal splits the week up into weekday, Saturday and Sunday. The reason for the different days being recognised is that each will have unique electrical demand features.

Take the domestic profile for example. During weekdays typically between 8am and 6pm the buildings will have little to no occupancy with people at work/school/etc thus the electrical demand will be low. Whereas on the weekend the occupancy rate of homes will be higher during the day leading to more constant electricity consumption. This is only one of the consumer profiles but it demonstrates why there needs to be a differentiation of the day of the week in the generic profiles.

As well as the difference in day, the fundamental change in electricity use depending on season needs to be factored in as each profile has different normalised values depending on the season of the year (Winter, Spring, Summer, High Summer, Autumn). Again this is needed as the distribution of electrical demand varies depending on season. An example of an generic profile is shown below for a domestic sector weekday in autumn.

Figure 2.3 Generic demand profile.



Source: Ofgem (2012)

This profile is, likely to different across different parts of the world reflecting differences in climate, economic development, as well as cultural and technological factors.

The first task to be achieved with these generic demand profiles was to create a generic year for each of the 12 sectors. This involved combining five generic weekdays (Monday to Friday) followed by a Saturday and Sunday (two weekend days for Ofgem profiles) to create a full week. Care was taken to ensure that the correct seasonal profile was used. In these generic year profiles each week would be an exact replica of the last with the only change in relative demand being when there is a seasonal change.

However, this is clearly not the case as the electrical demand is constantly varying and no two days will be exactly the same (some can be similar depending on conditions/day of the week, etc). This daily variation has to be taken into account by the use of a variation constant calculated below.

$$Variation\ Constant_{\ i} = \frac{Scottish\ demand_i}{Average\ demand_i\ (Season)} \qquad (2.2)$$

The demand model used takes temperature variation into account indirectly using this equation. It was mentioned previously that the full years demand profiles would be exactly the same (apart from season) but using the information from Equation 2.2, an adjustment to each is made. This "variation constant" is used to adjust each generic demand profile based on the electrical consumption for that specific day using Equation 2.3.

$$new\ normalised\ output_i = old\ normalised\ output_i * variation\ constant_{\ i} \ (2.3)$$

Appling the normalised constants for each half-hourly interval to each of the sector profiles give normalised varying yearly profiles for the 12 sectors. Using information on the total annual consumption by sector the electrical output for each sector at each half-hour interval was found by Equation 2.4.

$$Half\ hourly\ demand\ (MWh)_i = \frac{new\ normalised\ output}{\sum new\ normalised\ output} * Sectoral\ yearly\ consumption \qquad (2.4)$$

The output is a demand for each of the 17,520 half-hour periods in a year which will sum to give the sectoral demand.

2.5.2.4 Annual demand for each sector for the non-household sectors

Above we have given a method for separating generating the half-hourly electricity demand for this we need information on the sectors annual electricity consumption – the focus of this section

While there is information available on the domestic sales of electricity in Scotland, all other sales (industrial and services) are combined into one. Thus a method had to be applied to calculate the yearly sectoral demand to use in Equation 2.4.

Information available from the BEIS and the Scottish Government allows for the yearly sectoral demand to be calculated for the other 11 sectors (not including domestic) which are modelled. The energy in Scotland report (Scottish Government, 2014) gives information on the percentage shares of the 3 main sectors (domestic, industry, services) and these percentages can be applied to the BEIS overall electricity consumption figures (as they are based on raw data) to split the industrial and services electricity consumption.

With household and industry sector a demand now known it is necessary to further separate the services sector final demand. This separation is only possible as BEIS publish the overall UK consumption for these 10 services sectors (BEIS, 2014). Again in an ideal world it would be of benefit for the creation of ElSA that demand be split by SIC code and each SIC code having a sector specific demand profile. To determine the Scottish annual sectoral consumption scaling, as shown from Equation 2.5, is applied to each of the UK demand.

$$Scottish\ Sector\ Demand_i = \frac{U.K\ sector\ demand_i}{\sum U.K\ services\ demand} * \sum Scottish\ services\ demand \tag{2.5}$$

Fundamentally with the above equation (2.5) we have assumed that each Scottish services sector consumes the same share of overall services electricity as the corresponding UK sector. For example if the UK health sector consumes 10% of overall services electricity then 10% of overall Scottish services electricity consumption is attributed to the Scottish health sector. This seems a reasonable assumption as, unlike industry (which has large region variations), the size of the services sectors is dependent on population size rather than locations. As Scotland is part of the UK the same services are used (i.e the NHS).

Table 2.15: Scottish yearly sectoral consumption.

Sector	Scottish consumption (GWh)
Domestic	10,592
Industry	7,634
Offices	780
Communication	429
Education	743
Government	528
Health	534
Hotel	964
Other	387
Retail	2,749
Sport	442
Warehouse	984
Total	26,591

Source: Author's analysis

Above we have split the electricity consumption into the different sectors for households industry and services.

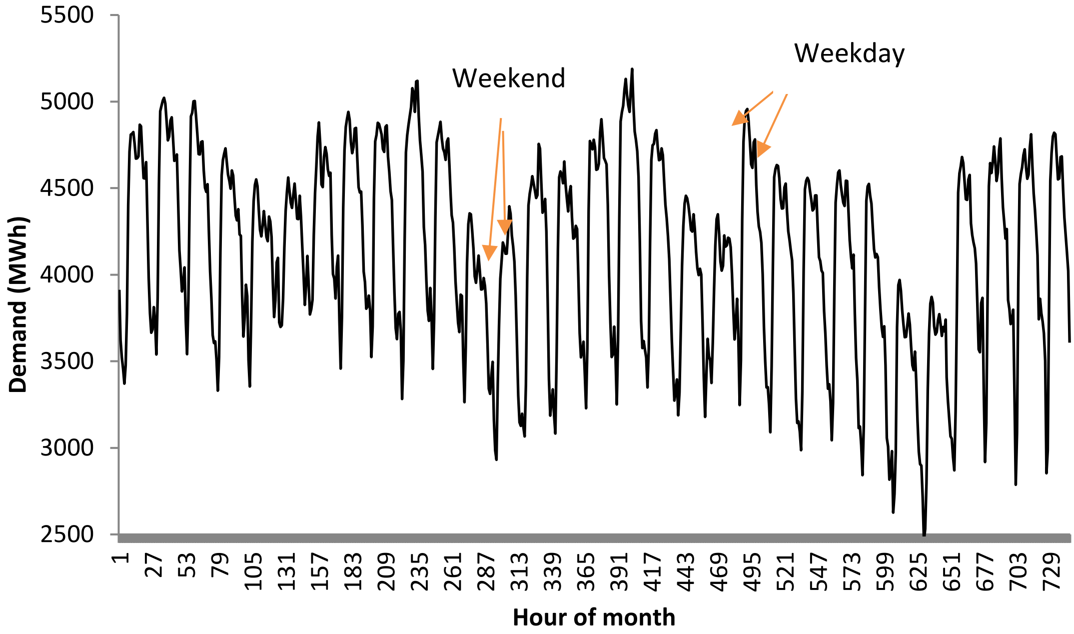
Even though we have used data sources from BEIS there is a disparity in the total electricity consumption and sales occurring as not all sales are metered. We account for this by calculating this unidentified electricity sector. This is done by using the estimated half-hour Scottish electricity demand (Equation 2.1). This is then compared with our modelled half-hourly created using the methodology described above. Equation 2.6 calculates this undefined consumption.

$$Undefined\ demand(t) = Estimated\ half\ hourly\ demand\ (t) - \sum Scottish\ Sector\ Demand\ (t) \quad (2.6)$$

As our model only incorporates metered data there is a slight difference – which we allocate to ‘other’ consumption sector.

By incorporating this undefined sectoral consumption into our model we now half half-hourly electricity consumption by 12 sector for 2012. Figure 2.4 demonstrates an illustration of the total electrical consumption for Scotland for a month in half-hourly intervals.

Figure 2.4: Scottish electrical consumption May 2012.



Source: Author’s analysis

Clearly the daily and weekly variations of electrical consumption can be seen. Each weekday there is a large peak during the late afternoon, when people are finishing work. In terms of the variations throughout the week we find that there is clearly a pattern of workdays and weekends. The demand for electricity at the weekend is lower - driven by less consumption in industry and services.

With the total generation (by source) and consumption (by sector) now known for each half-hourly period, imports, domestic use and exports can be calculated at each-timestep. We explain this in the section below.

2.5.3 Imports, domestic use and exports

Now we have the supply (by generation) and demand (by sector) we can use this information for calculation a range of consumption variable, e.g imports and exports – which is the focus of this section.

2.5.3.1 Calculation of imports

In general Scotland is a net export of electricity i.e. more electricity is exported than imported. The two integral connections which Scotland exports and imports electricity are the B6 boundary which connects to England and the interconnector across the Irish Sea which connects to Northern Ireland. For 2012, according to BEIS (2017b), Scotland exported 2,164 GWh of electricity to Northern Ireland while only importing 1.93GWh and for the England connection 11,123GWh of electricity was exported with 406GWh imported. This is likely to change over time as conventional power plants in Scotland begin to come offline in favour of more low carbon technologies. At times of low wind and high demand Scotland is going to need to rely on the rest of the UK to 'keep the lights on' (Gill and Bell, 2017).

In our supply/demand match model, the exact imports from Northern Ireland are known at each half-hourly times step as this is monitored data available from the Elexon portal. When investigating this data it was found that Scotland basically did not import any electricity (<0.5%) from Northern Ireland, thus all the Scotland imports must come from the connection with England. Information on these (England-to-Scotland) imports is not recorded and as such assumptions had to be made in our demand model. Since electricity cannot be stored (apart from pumped hydro) it was assumed than if the generation in Scotland was less than Scottish demand[36] then the supply deficit was made up from the rest of GB. When doing this our total imports matched well with the recorded BEIS figures (BEIS 2016a)[37]. As the Elexon portal holds information on generators across the full GB, grid imports could be separated by technology using Equation 2.7.

$$Import\ by\ technology_i(t) = \frac{R.GB\ generation_i(t)}{\sum R.GB\ generation(t)} * imports\ (t) \qquad (2.7)$$

In the above equation imports by technology is based on the share of the technology in total electricity generation at each time step. For example, if coal generation was responsible for 40% of all generation at a half-hour period then Equation 2.7 assumes that 40% of the imports are attributed to coal for that time-step. Also from equation 2.7 the imports are based on the rest of GB (RGB) generation mix at each time step which is the total GB electricity minus Scotland – as Scottish generation is not involved in imports.

2.5.3.2 Calculation of Scottish domestic use electricity

For the purpose of the development of our ElSA there are four sources of domestic electricity consumption listed below:

1. Losses
2. Generators own use
3. Pumped storage
4. End user

As this is a model of the electricity sector we must account for the fact that there will be losses in the system, like every other physical system. In the UK there are two main types of losses, technical and non-technical (Navani et al, 2012). Technical losses stem from the fact that the electrical network is a system which is transporting a form of energy. Most losses are

[36] Including losses and generators own-use.
[37] These comparison can be found in Appendix 2B.

resistance losses where electricity will be lost (in the form of heat) due to the friction in the cables. Other types of technical losses are open/closed circuits and efficiency in transformers. These technical losses are well studied (BEIS, 2016b) and can be accounted for accurately as they are a function of the amount of electricity on the system.

The same cannot be said for non-technical losses as these are mostly caused by elements which are not related to the transportation or transformation of energy. By far the most common form of non-technical loss in the UK is cable theft, which mostly occurs on the distribution system. As theft, as with all non-technical losses, are essentially random there is no way to accurately model their associated losses in the grid. Because of this we combined the technical and non-technical losses from BEIS (2016b) to estimate the losses at each time step by:

$$Losses\ (t) = \frac{Generation(t)}{\sum Generation} * \sum Losses \quad (2.8)$$

These losses can be separated by technology by applying technology share equation by time step.

$$Losses\ by\ technology_i\ (t) = Technology\ share\ _i(t) * \text{Losses (t)} \qquad (2.9)$$

$$Technology\ share_i(t) = \frac{Generation\ by\ techology_i(t)}{\sum Generation\ by\ technology\ (t)} \quad (2.10)$$

From Equation 2.8 the losses at each time-step are related to the amount of generation at that time-step. For example if at the time-step 1% of the total yearly electricity was generated then 1% of the yearly losses would be attributed to the time-step. It is advantageous, for the purpose of ElSA, for these losses to be associated with the different technologies – as is the case in Equation 2.9. In a similar manner to the imports the technology share (Equation 2.10) calculates the percentage contribution of each generation technology at each half-hour time step. These shares are then used in the calculations of the different technologies contribution to a variety of variables, like has been done for losses in Equation 2.10.

Another source of domestic consumption within Scotland was by the generators themselves. In the generation process generators rely on electricity to operate thus they will consume electricity. This information is contained within the Elexon portal as along with the FPNs and BOAs there is information on the generators own demand at each half-hourly time-step.

Pumped storage is one of the only economical viable ways in which electricity can be stored. The principle of operation is similar to that of a conventional dam hydro system but can work in both directions. In a conventional hydro system the potential energy of water in a reservoir is converted into kinetic energy by flowing water from the reservoir through a turbine which converts this kinetic energy into electricity. Whereas in a pumped hydro system the water can also flow up the reservoir by the use of a pump (which uses electricity) and can be then used to generate electricity at a later time. The overall efficiency of a pumped Storage system is between 70-80%, this efficiency determines how much electricity is generated by the plant compared with that used to pump the water back up the reservoir at the earlier time. Pumped storage systems are usually operated when there is there is a lull in demand or excess generation (amounting to cheap electricity) on the system which can then be used to pump up the reservoir for generation at peak times. For Scotland this would happen mostly in early morning i.e 12-4am when non-despatachable plants are running but there is not much demand. In Scotland there are two large pumped storage plants, Cruachan and Foyers, with a combined capacity of 740MW.

In the Elexon data for these two plants indication is given to when they are operating as a generator or storage by a change of sign[38]. When operating as a generation unit the pumped storage becomes part of the supply of electricity but when operating as storage – acting as a demand of the system - the amount of electricity by technology used for pumped storage can be calculated using the following equation.

$$Pumped\ storage\ by\ technology_i\ (t) = Technology\ share\ _i(t) * \text{Pumped storage (t)} \tag{2.11}$$

Similar to Equation 2.10, Equation 2.11 attributes the electricity used in pumped storage by technology based on the technology share at that time-step.

[38] Positive values indicate that the plants are generating whereas negative values means they are using electricity for to pump water back up the reservoir.

The final element of consumption for Table 2 of the ELSA framework is end use consumption, this is the electricity that reaches a final destination to operate an appliance. This consumption is found from the demand model previously explained and the consumption by sector, by technology can be identified by Equation 2.12, using the same technology share method as that for Equations 2.10 and 2.11.

$$Sectoral\ consumption\ by\ technology_{i\ j}(t) = Technology\ share\ _{i}(t)* \\ Scottish\ Sector\ Demand_{j}\ (\mathrm{t}) \qquad (2.12)$$

As previously identified the ElSA contains information on the generators own use of electricity, this comes directly from the Elexon data.

2.5.3.3 Calculation of exports

For imports of electricity the assumption was made that if the volume of generation in Scotland was less than overall demand for electricity in Scotland then imports would be needed from the rest of the GB. The opposite assumption can be made for exports, if the generation in Scotland is higher than the domestic demand then the electricity must be exported. Again, for Northern Ireland the exact imports are known though the Elexon portal. Whereas for the exports via the English connection exports are found by the following equation:

$$Expots\ R.GB\ (t) = Total\ generation\ (t) - Losses(t) - Generators\ own\ use\ (t) - \\ Pumped\ storage\ (t) - \sum sectoral\ demand\ (t) - Exports\ NI\ (t) \qquad (2.13)$$

The exports by technology are calculated by:

$$Exports\ by\ technology_{i}(t) = Technology\ share\ _{i}(t) * Exports\ to\ RGB\ (t) \quad (2.14)$$

As the exports to the rest of GB is the excess generation at each time-step, this has to be calculated from Equation 2.13. Using this equation, at each half-hour time-step, the excess electricity is calculated from the total generation minus the different types of electricity consumption. Also, as with the other consumption variables RGB, exports can be separated using the technology share as found in Equation 2.14.

In Appendix 2C the values calculated from this half-hour model are compared with the published values from BEIS.

2.5.4 Conversion from physical units to cost of electricity

Initially the model is developed in physical units but as the purpose of the ElSA was to expand the SNA framework and economic impacts, it is necessary to convert these data into monetary terms. Doing this ensures that the ElSA is consistent with the SNA framework units. In order to do this we use the information available on the price of electricity at each hourly time step from Nordpool[39].

Nordpool is the largest electricity market in Europe which operates in 9 countries, the UK being one where Nordpool run the N2EX day ahead market[40]. Day ahead markets work by a buyer (utility) predicting how much electricity they will need for the next day and entering into agreements with generators to buy electricity. The average price of these interactions for each half hour period is given by the UK Nordpool. In principle the utilities have agreed to buy electricity from a certain generator but in reality the system will not work like this due to the nature of electricity. All electricity generation is mixed in the system and there is no way of being able to exactly trace the moment of electricity from a generation station to final use.

In practice, the electricity market sets a price at which each generator will sell, and a utility will purchase, a certain amount of electricity. This helps in our modelling as we can say that all generated electricity (in each timestep) is put in a 'pot' at which sectors use and the average price from Nordpool will give the overall cost of electricity sold. With energy markets the price of electricity is constantly changing. In general, each day will follow a pattern of lower energy price when demand is low and a higher price when the demand is high. The figure below demonstrates this fact, taking a typical day in May 2012.

[39] https://www.nordpoolgroup.com/
[40] In 2017 ~38% of UK electricity was traded on this market.

Figure 2.5: Daily variation of electricity price.

Source: Nordpool (2018) & Elexon (2016)

Figure 2.5 demonstrates that the electricity price has a clear relation with the demand. We find that in the early morning there is a clear increase in demand, which is matched by an increase in electricity price. During the work day there is near constant electricity demand, with little variation in the electricity price. Similar to the morning there is a clear increase in both demand and price in the late afternoon with a peak being reached. There is a slight offset between the peaks but still see that there is a clear relationship between electricity piece and demand.

To go from physical units to revenue a simple multiplication is carried out of price (£) multiplied by the quantity (MWh). By converting each time-step in this way, depending on electricity price at that timestep, is much more advantageous than applying a single 'average' price of electricity. This half-hourly electricity price allows for the different principles of operation by each technology and effect on economy to be measured that is otherwise missed within the SNA framework. In our satellite account we are assuming the market price is the price received by the generators (i.e wholesale cost).

2.6 Population of Tables

In Section 2.3 of this thesis the transfer from tourism to electricity was explained with an ElSA framework given. This section gives information on how the tables were populated for the first ElSA for Scotland 2012, using the data obtained in the steps described in Section 2.5.

2.6.1 Table 1

For Table 1 the expenditure of the imports by technology is needed. This come from the demand supply model detailed in section 2.5. Using the import information gathered from Equation 2.7 along with the cost of electricity the columns E1.1-E1.12 within the SNA framework can be populated. For each row within column E1.13 a simple calculation is carried out to determine the percentage each technology contributes to import expenditure.

2.6.2 Table 2

Similar to Table 1 of the ElSA framework, Table 2 – which focuses on the expenditure of domestic use electricity – is filled using the information from the supply/demand match model. For the consumption by the different sectors (E1.1-E1.12) Equation 2.12 is used, with Equation 2.11 (E2.8) for losses and Equation 2.11 (E2.2) for pumped storage. As has been mentioned in development model there is also own generation (E2.3) available from the Elexon portal. Each of these variables are again converted into monetary terms using the half-hourly electricity price.

2.6.3 Table 3

With the expenditure of exports (Table 3) the final sector of consumption is not of importance, only the region of consumption. For the Scottish ElSA model this relates to Northern Ireland (E3.1) and England (E3.2). Elexon portal produces information on the exact flow of electricity between Scotland and Northern Ireland which along with the COE is used for the population of column E3.1. Whereas for the England exports, the POE is used along with Equations 2.13 and 2.14 of the supply demand match model.

2.6.4 Table 4

TSA Table 4 was a combination of two tables to give the important outputs for tourism. Table 4 for the ElSA does the same for electricity with the data coming straight from Tables 2 and 3. This is demonstrated in the ElSA framework section (3.3).

2.6.5 Table 5

The first four Tables of the ElSA framework, similar to that on the TSA, deal with the electrical consumption of products. Table 5 focuses on the supply side of the electricity products and similar to the TSA framework is a production account. As shown in Figure 2.2 this is a products by industry account based on the information from the published IO tables from the Scottish Government (2018).

As the focus is on the domestic supply of electricity, the first stage was to convert the combined use table, which includes imports, into a domestic use table. This was achieved by using data used in the development of the original 2012 Scottish IO[41] . Using this data allows for the cell by cell calculation to made eliminating the imports, taxes etc from the original IO, converting it from a combined use product by industry table to a product by industry domestic use one.

For the production account, the generation products by industries section is populated using the generator own use and pumped storage (Equation 2.11) data from Elexon. The other products (row) and other industries (column) are populated using the information from the

[41] We would like to thank the Scottish Government for use of the data which allows for the conversion from a combined use table to domestic use.

domestic use table described above. Finally the GVA for each generation industry was calculated from a range of source (this is detailed further in Section 3.5)

2.6.6 Table 6

Table 6 of the Scottish ElSA brings together the information found in Tables 1-5 to give an overall picture of the economy, with a focus on the electricity sector. Contained in this table is the total output from the products in Table 5 along with the exported electricity by product from Table 3. This allows for the total output to be given in basic prices.

Along with the information above data regarding the taxes and subsidies was taken for each product to convert the prices into purchaser prices. For the electricity sector there was one main tax and one main subsidy taken into account. The tax was the climate change levy which is a tax depending on the amount of electricity produced for fossil fuel plants, thus to calculate the rate is applied to each MWh of electricity produced from these plants. For the subsidies information on the ROC is public available for hydro and wind.

Together with the above data, for Table 6 of the Scottish ElSA information is required on the taxes and subsidies the technologies. Identified in Chapter 1 the ROC scheme was in place during 2012 with generators receiving income for each MWh that they produce, for Wind /Hydro and Other generation this information is available from the renewables and CHP register[42].

The tax which was put on fossil fuel generators during 2012 was the Climate Change levy (CCL). This is a tax whereby the generators are charged for each MWh of electricity charged thus to calculate the overall tax the MWh produced is multiplied by the tax rate.

[42] Link: https://renewablesandchp.ofgem.gov.uk/

2.6.7 Table 7

Similar to the TSA framework the employment table is one which is not directly linked to the others but is still a core table. For this table we used information contained within the UK business register and employment survey. The BRES database contain the full-time and part-time employment by level 5 SIC code, this means that we can separate generation employment from the other parts of the electricity sector. Using this database we were able to map each location and link them to a generation technology.

2.6.8 Other Tables – Emissions

One of the non-core tables included in the Scottish ElSA deals with the emissions of each technology, which, with the push towards a low carbon society, is important to understand. In theory there could be two types of emissions tables created. One for point source (operating) emissions and another for life-cycle emissions, however ElSA tables are point source emissions[43] as these are the most quoted. As such the emissions in operation are of most importance for coal and gas power plants. We could have applied an average coefficient for the emissions per MWh of electricity for each of these technologies. However this would not be the most accurate measurement as coal and gas plants will emit different levels of CO_2 depending on their age and technology. Fortunately for this project the SEPA (Scottish Environmental Protection Agency) records the total CO_2 emissions for every coal power plant in Scotland[44]. Using this database and the Elexon generation data the CO_2 emissions per MWh of each coal and gas power plant in Scotland could be accurately calculated.

An extension of the ElSA is that each of the first 4 tables can, using the CO_2 emission data, can be converted into emissions from monetary – which could bridge the gap between

[43] Point source emissions are the emissions which happening during only the generation of electricity via fuel etc. Life-cycle emissions take into account the development, operation and decommission of plants

[44] http://apps.sepa.org.uk/spripa/Search/Options.aspx

electricity satellite accounts and environmental accounts. Doing this would give information on the emissions of different consumers by products.

2.7 Results

In this section there are two sets of results, the first (2.7.1) are focused on showing the data in each table then section 2.7.2 outlines the extra outputs that can be calculated through the development of the tables. Section 2.7.1 gives aggregated variations of the tables to give the main points, the tables can be found in full in Appendix 2B.

2.7.1 ElSA Tables

First the expenditure by Scottish electricity used on imports by generation technology is summarised for Table 1 of the Scottish ElSA below

Table 2.16 Aggregated Table 1 of Scottish 2012 ElSA.

Products	**Imported electricity expenditure (£m)**			
	Domestic	….	Retail	Total imports
Coal	3.14		0.77	7.99
Gas	2.64		0.65	6.83
Nuclear	1.54		0.38	3.90
Flow	0.06		0.01	0.15
Pumped generation	0.08		0.02	0.21
Wind	0.06		0.02	0.16
Other	0.02		0.01	0.05

Source: Author's calculation

Table 2.16 shows that electricity imports are dominated by output from conventional power plants, with 41.4% of the imports from coal and another 35.4% from gas. This dominance of imports from conventional power plants is somewhat expected. As explained earlier, the penetration of renewables is much higher in Scotland than the rest of the UK, but these are highly intermittent and at times do not match well with Scottish electricity demand peaks. As these times Scotland must rely on the UK grid to meet this gap supply which will mean the output of conventional power plants.

The next table of the Scottish ElSA was the Scottish domestic consumption of electricity (Table 2).

Table 2.17: Aggregated Table 2 of Scottish 2012 ElSA.

Products	**Domestic use electricity expenditure (£m)**			
	Households	..	Losses	Total Domestic use
Coal	117.79	..	27.81	389.23
Gas	55.79	..	13.17	180.83
Nuclear	166.87	..	39.27	551.53
Flow	47.95	..	11.17	150.15
Pumped Generation	8.15	..	1.77	26.04
Wind	75.87	..	19.24	240.62
Other	20.19	..	4.72	64.70
Total	492.61	..	117.16	1603.11

Source: Authors calculation

By far the most commonly used form of electricity in Scotland in terms of expenditure is nuclear energy which comes as no surprise. To be economically viable nuclear power stations must operate at near full capacity at all times and Scotland has two nuclear facilities - a relatively large proportion of nuclear power stations with regards to population size. Scotland has a population of ~5.4 million and 2 nuclear power stations (2.6MW capacity) whereas if this is compared to England there are 6 nuclear power stations (6.6MW capacity) for a population of 54 million. We estimate that for, nuclear power was responsible for around 34% of the total domestic electricity expenditure in Scotland (£552 million/ £1603 million). The second most domestically used electricity (by expenditure) is coal, for which in 2012 there were two large plants operating in Scotland.

Within the standard SNA framework this information on the electrical consumption (by sector and value) is not available With Table 2 of the ElSA framework allows use to find the expenditures on electricity generation by technology and where it is being used. This can aid in policy questions as there is clear indication of value of electricity generated by the different technologies.

Table 2.18: Table 3 of Scottish 2012 ElSA.

Products	**Exported electricity expenditure (£m)**		
	England	Northern Ireland	Total exported
Coal	107.98	23.40	131.39
Gas	54.72	11.58	66.30
Nuclear	148.16	35.38	183.54
Flow	49.84	9.62	59.45
Pumped Generation	5.71	1.53	7.24
Wind	105.19	15.26	120.45
Other	19.86	3.99	23.86
Total	491.47	100.76	592.23

Source: Author's calculation

One of the most eye-catching figures when comparing Tables 2 and 3 of the Scottish ElSA is the expenditure of domestically used (£240 million) and exported (£120 million) of wind energy 33%[45] of the total expenditure on wind from exports – the largest of the generation technologies. A fact that is lost in the standard SNA framework.

This again down due to that wind is a non-dispatchable technology and needs to be used when it is available. As there is only so much wind that consumers in Scotland can use the connections to Northern Ireland and England enables this electricity to be exported.

In the future an increase in wind capacity may be a problem for the grid with too much electricity on the system at the one time, causing variation in the frequency of the network. This is a fact recognised by NG and as such there is work ongoing to reinforce the grid connection between Scotland and England and enable higher capacity of electricity to flow in both directions.

[45] (£120 million)/(£120 million + £240 million)

As Table 4 is a combination of Tables 2 and 3 there is no need to include it in the main body of this chapter however, a version can be found in Appendix 2B. In this appendix also contained is the the full production account (Table 5), below is presented is Table 6 which combines the information from Tables 4 and 5.

Table 2.19: Table 6 of Scottish 2012 ElSA.

Products	Supply of Scottish electricity (£m)					
	Output of producers	Exports	Taxes Less Subs	Domestic supply	Domestic demand	Domestic Use Percentage
Coal	243.6	131.4	37.0	412.02	117.8	48.3%
Gas	111.9	66.3	15.0	193.17	55.8	49.9%
Nuclear	345.4	183.5	0.0	528.94	166.9	48.3%
Flow	91.0	59.5	-128.8	21.68	47.9	52.7%
Pumped generation	16.1	7.2	-6.2	17.16	8.2	50.6%
Wind	145.5	120.4	-322.0	-56.04	75.9	52.1%
Other	39.8	23.9	-17.9	45.75	20.2	50.8%
Electricity non-generation	2694.7					
Other non-electricity	61,972					
Value added	55,501					

Source: Author's calculation

In Table 2.19 we see that the subsidies for the renewable energy technology dwarf the government income from the climate change levy i.e total taxes (minus subsidies) for electricity generation were -£423 million in 2012.

In the TSA there are several key aggregates which are usually reported: internal tourism expenditure and tourism direct gross value added.

Again if we mirror these aggregates for the electricity sector we find that a total internal electricity expenditure of £2.2 Billion (Table 4); electricity generation GVA of £1.36 Billion (Table 5).

With some of the key information from the tables detailed. the next section describes useful variables from outwith the tables.

2.7.1 Variables calculated using the data from ElSA development

The previous section has investigated the outputs of the core tables of the Scottish ElSA. With the creation of the ElSA there is much more information regarding the relationship between electricity and the economy which can be determined. In this section, we discuss two important aspects of electricity market: price of electricity by different technologies, and the temporal pattern of export/import between Scotland and the rest of the UK.

2.7.1.1 Average Price of electricity

In the development of the Scottish ElSA the hourly variation of the electricity price was taken into account, meaning that the average price of electricity sold for each of the technologies is easily calculated using the equation below.

$$Avg\ COE_i = \frac{\sum Generation\ by\ techology_i(t) * COE\ (t)}{\sum Generation\ by\ techology_i} \quad (2.15)$$

At each half hourly time-step the total expenditure for a technology is given by the technology output (in MWh) multiplied by the price of the electricity – from the Nordpool database. Summing each half-hour times-step gives the total yearly expenditure for a technology, which is then divided by the total generation by technology to give the average POE.

This average price of electricity allows for investigation into the different principle of operation of the two different generation plants. Table 2.20 displays these average cost of generated electricity over the year.

Table 2.20: Average price electricity by technology.

Products	Average cost (£/MWh)
Coal	46.70
Gas	46.23
Nuclear	45.53
Flow	47.14
Pumped Generation	54.92
Wind	44.31
Other	48.05
Total	46.04

Source: Author’s calculation

The highest price of electricity, by quite some distance, is pumped generation which is to be expected. Pumped storage is used mainly for fast-reacting peak demand generation, thus at times when the electricity price is the highest – as demonstrated in Figure 2.5. Coal and gas power plants have similar average prices of electricity demonstrating that they both have similar operation principles when as they both have variable output to meet demand.

In Table 2.20 we see that the two lowest average price of electricity are nuclear and wind energy. By needing to operate close to 100% capacity at all times means that the nuclear stations will be affected by the decrease in electricity price just as much as an increase. For wind energy the low average cost of electricity is a result of the need to be used when available and even if the demand, and price, of electricity are low. This information regarding the average cost of electricity can be useful in the disaggregation of IO accounts, as explained in Chapter 3.

2.7.1.2 Temporal pattern of exports and imports

It is not only the average cost of generated electricity which is of interest; the average cost of both imports and exports is shown in Table 2.21. The calculation for this is similar to that found in Equation 2.14, with the difference being that instead of generation by technology the focus is on either imports and exports (by location).

Table 2.21: Average cost of imported and exported electricity.

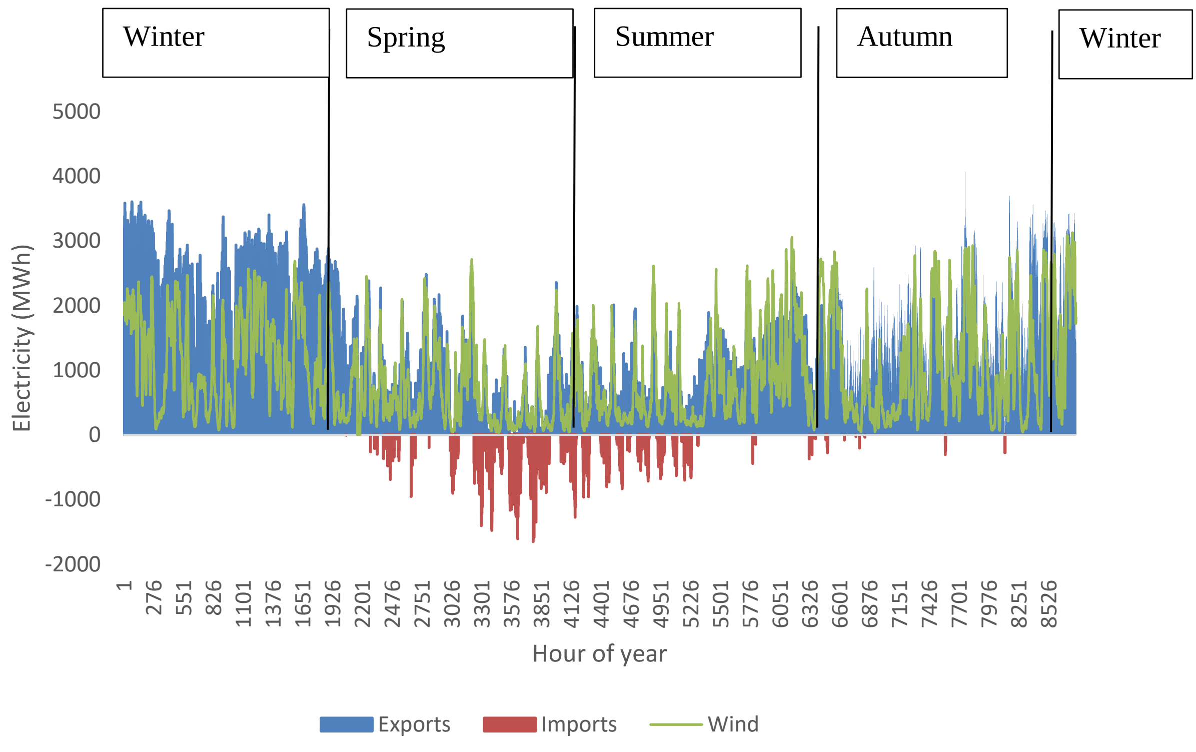
	Average cost (£/MWh)
Exports England	44.71
Export NI	46.36
Imports	47.77

Source: Author's calculation

Table 2.21 with the variation in average price gives indication of the times in which the electricity is being imported and exported and idea of how the Scottish grid interacts with the rest of the UK. The highest cost out of the three is for imports, which happen at peak demand. From the table we find that the average cost of electricity of exports to England is more than £3 lower per MWh than imports, indicating that at times of low demand electricity is being exported. For the NI interconnector the story is different with the average cost of exports actually being greater than the average cost of generated electricity. This is because in 2012 the connection from Scotland to NI did not operate as a conventional interconnector where there was a reversal in flow. Rather there was a continuous flow from Scotland to NI which would act as a constant base consumer on the Scottish network. This however has started to change as more Irish wind power has started to come online and be exported to the GB network.

The data acquired from the development of the Scottish ElSA is also beneficial for investigating the import/export variables, other than expenditures. As the Northern Irish connection functions as a constant demand, in at least 2012 data, this section is focused on the connection between Scotland and England. When investigating imports it is useful to look at the pattern of when Scotland was operating as an importer or exporter, shown in Figure 2.6 below.

Figure 2.6: Scottish exports and imports time path.



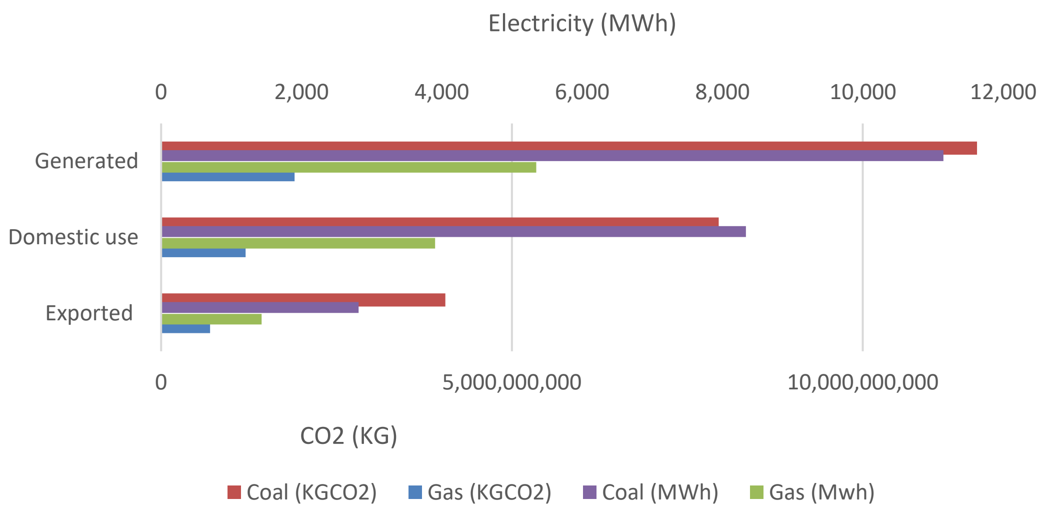
Source: Elexon data and Author’s wind model

In terms of absolute value, exports dwarf the imports (10,992 GWh exports to 404 GWh imports), however by number of hours Scotland is an importer of electricity 11.52% of the time. The graph above suggested that Scottish exports and imports tend to be a function of wind generation. We find that there is some correlation between the amount of wind generation and the level of exports and when there is low levels of wind generation the imports increase.

Also, as this is 2012 there were two operational coal power plants in Scotland, but as of 2016 both are closed meaning the graph above would likely change dramatically. With no coal power plants the value and number of hours in which Scotland is importing electricity is likely to rise, which will be negatively correlated with wind generation. Whereas the value and output of exports is likely to fall while still following the path of wind generation.

Emissions are important when investigating the electricity sector, especially with a world-wide emphasis being put on reducing climate change and the ElSA can be used to investigate these. For example, Figure 2.7 below gives an illustration of the emissions of the coal and gas plants in Scotland in 2012 broken down by domestic use and exports.

Figure 2.7: Scottish CO_2 emissions and the usage[46].



[46] There are other usages not included and as such the total is greater than sum of exports and domestic Scotland – These include auto generation and losses

Source: Author’s calculation

As is to be expected the coal emissions are much greater than that of gas emission, around 6.4 times greater. The main reason for the higher levels of CO_2 emissions by the coal is the greater level of electricity generation. However, the total coal generation was only 2.11 times higher (in physical terms) than that of gas thus indicating that the coal plants are ‘dirtier’ than the gas ones.

As has been found in this section there are several other variables (other than the tables) which can be determined with the creation of an ElSA. In the next we section we detail the reproducibility of the ElSA framework.

2.8 Reproducibility of ElSA methodology

We have shown how ElSA can be constructed, building on the detail in a SNA framework, to provide useful data on the electricity usage of economic activates. One of the main purpose of the detail provided is to support the production of similar accounts for other regions and countries worldwide. In this section we reflect on the usefulness and reproducibility of an ElSA.

2.8.1 Tables 1-4

2.8.1.1 Other regions within the UK

Firstly we determine if the reported ElSA methodology for Tables1 to 4 could be applied to other regions of the UK. Initially, in the creation of the Scottish ElSA, we used Equation 2.1 to calculate Scottish demand at each time step by using the overall GB demand. This may prove difficult to apply to other regions as we estimate the Scottish demand using information on the England and Wales demand.

In the Scottish model the next stage was to build the yearly demand profiles a process which is easily transferable to other regions of the UK as the generic profiles would be the same as they come from Ofgem and Elexon.

The final stage of the creation of the Scottish demand model was to apply these profiles to sectoral demands. These could not be straightforwardly applied to other regions as the UK as information for this was taken from the Energy in Scotland report (Scottish Government, 2014).

The methodology used for the creation of the Scottish ElSA Tables 1 to 4 required the generation from each electrical power station to be known at hourly time steps, for Scotland this was taking from the Elexon portal. Elexon also holds this generation information for the other regions of the UK thus making it easy applicable.

It was previously mentioned in this chapter (Section 2.4) that the unique political and geographic characteristics of Scotland aided in the creation of the ElSA. This is of most importance for the imports and exports tables of ElSA. It is known that Scotland only has two ways to import/export electricity through Northern Ireland and England, both of which are parts of the UK. For the Northern Irish import/exports the flow of electricity is directly measured and the exports/imports to England can be estimated. However, if we were to apply this methodology for other regions of the UK it would prove difficult as most regions are interconnected to several others as part of the UK and there are few measurements of the flow between them as they are on the same transmission system. It could not be determined which region was being exported to or imported from as there are as it is seen as the one large grid with several unmeasured connections.

Overall the methodology defined for Tables 1 to 4 could not be applied easily to other locations within the UK.

2.8.1.2 Other countries

As identified above it would be difficult to apply the ElSA demand model methodology to other regions within the UK. In this section we investigate the reproducibility of the methodology for other countries with particular attention paid to GB grid as a whole.

Applying the methodology to generation demand profiles by sector for the full GB would in fact be more accurate than Scotland only as the creation of the Scottish ElSA demand model used assumptions from overall GB data and UK demand profiles from Ofgem (2012).

Again, as with the demand part of the model, the Scottish ElSA methodology of determining the half-hourly generation could be applied as the Elexon portal contains the necessary information on the GD grid.

For the imports/exports tables (1,3) for the GB grid as whole the methodology used could be applied to an extent. As with Scotland, the geographical location of the UK actually aids in respect to creation the import and export tables of an ElSA. The GB grid has 3 interconnections with other countries; Ireland, France and the Netherlands all of which are monitored meaning the exact overall imports and exports to each can be found for each half-hour time step. This is good for exports as the exports can be calculated by generation type using Equation 2.14. However to measure the imports by generation information would have to be found for the generation mix at each hourly time step for the 3 countries. The France generation mix at each hour is easily found using French BM reports available on the public domain but the Dutch and Irish information is harder to source.

The success of applying the supply demand match model used was to be replicated for Tables 1 to 4 for other countries depends on how advanced their electrical network is and if they have accurate measurements. To apply the methods measurements would be requited on hourly total demand; generic demand profiles; yearly sectoral demands and half-hour generation by type.

The reproducibility of the export/import methodology to other countries really depends on their location and if how many connections they have to other countries and whether the connections are monitored at a high level. In general the more connections to other countries implies greater difficulty in using the ElSA method. Also to apply the full methodology the generation mix of each of the connected countries will have to be known which again increases in difficulty as the number of connections increases. An example of this in a European context would be that it would be more likely that the ElSA methodology could be applied easier to

Portugal which has one interconnection (Spain) than France which is connect to 6 other European countries (Germany, Belgium, Italy, Switzerland, Spain and the UK).

While the methodology is difficult to apply for other regions of the UK it could be applied straight to the GB grid as a whole. The clear exception would be the import table. The reproducibility of the ElSA methodology will also vary greatly depending on the location on the country in question as well as the availability of data. It would be hoped that over time as smart meters become the norm that the methodology outlined would be a base used to create electricity satellite accounts worldwide. If we do look at GB for example it shows the ElSA methodology framework can work for more than just Scotland and when more data becomes available they will become more accurate.

2.8.2 Tables 5-7

With the methodology of the ElSA being of importance, as with Tables 1-4, some comment has to be made on the reproductively of Tables 5-7 of the Scottish ElSA. For Table 5 of the Scottish ElSA a domestic use table was developed from the combined use table and data from the Scottish government.

Only one region (Wales) within the UK other than Scotland has their own economic IO tables. It is plausible that the method from the creation of Table 5 of the Scottish ElSA could be easily applied to this region. But there are no other official published regional tables making it difficult. On a national scale the methodology for Table 5 could be developed as many nations worldwide have some form of economic accounts linked to the SNA framework. Table 6 is a combination of Tables 4 and 5 plus information on the taxes and subsidies of the electricity generation sector. Thus meaning that the reproductively of Table 6 for any other region/nations depends highly on how readily available the taxes/subsidies information is.

2.9 ElSA development conclusions

The electricity sector, due to its size and nature, is one of high importance within the economy as a whole. However, with this being said, economically within the internally recognised SNA framework it is not treated as such due to high level of aggregation. Within the SNA framework the distinct elements of the electricity sector are aggregated to a single one allowing for information to be lost or hidden. To overcome this, an Electricity Satellite Account (ElSA) for Scotland for 2012 was developed. The contribution of this chapter is that, to the author's knowledge, this is the first attempt at the development of an ElSA. Satellite accounts have been used before to extend the analysis of economic sectors without interfering with the SNA framework, but never for the electricity sector. As such there was is no standard method for developing ElSAs

With this being the first attempt (to the authors knowledge) at creating and ElSA we first develop a methodology for creating such accounts. In the development we 'borrow' and adapt the principle of the TSAs – the most widely used satellite accounts - for electricity generation. As with the TSA, the ElSA harbours information of the supply and demand of electricity.

Overall in the Scottish ElSA there were seven tables created in the ElSA methodology which are (in order): imports by expenditure, domestic use by expenditure, exports by expenditure, total generated by expenditure, production account, total domestic supply and employment. Along with these tables was a large data acquisition which allows for further investigation into the electricity sector otherwise unidentifiable in the SNA framework, such as the average cost of a generation technology or emissions.

Outlined in the literature are four key questions which must be answered by any satellite account, below we determine have these questions being answered by the Scottish ElSA methodology.

– 1. What resources does the sector use?

In the Scottish ElSA we are able to determine the electrical consumption of a range of economic sectors. As we use half-hourly data on the Scottish generation we can match the sectoral electricity consumption by technology. This adds to the current as in the SNA framework we only see the sale of the aggregated electricity sector (which includes generation, transmission and distribution) to other sectors, but using the ElSA we can determine the flows for the generation sectors to other sectors.

– 2. What is being produced and by whom

As with the previous question the development of the Scottish ElSA allows for determination of the generation by technology, again adding detail to the SNA framework.

– 3. Where does the production come from?

Electricity networks are not developed in isolate, instead they form part of a larger network (i.e the Scottish network forms part of the GB network which in turn forms part of the European network). With this interconnectivity there will be flows of electricity between networks thus this question of where production come from is very relevant for the electricity sector. In the development of the Scottish ElSA, as well as looking at internal generation and consumption, we also focus on the electricity which is imported and exported. As with the two previous questions this adds to the information found with the SNA framework.

– 4. What is the overall expenditure and where does it come from?

One of the key contributions of the ElSA methodology is that we account for the half-hourly variation in electricity price to calculate expenditure. Using the Nordpool data base we know the half-hourly price of electricity which we multiply by the physical value of electricity at time step to give the cost of electricity. Totalling these half-hourly expenditures gives the yearly expenditures. Not only can we calculate this expenditure for the overall electricity generation sector but, as we know the half hourly generation by type and sectoral consumption, we can calculate the sectoral expenditures by technology.

The impacts of using this half hourly price of electricity for economic modelling is explored in the next chapter

The development of this ElSA framework is a key contribution to this PhD thesis. Previously Teliet (1984) had identified the possibility of an energy/electricity but this is the first attempted at developing an ElSA framework (through the adaptation of the TSA framework) with an accompanying full account for Scotland in 2012.

This full account gives a better understanding of the electricity sector than otherwise found within the SNA framework. In the first 4 tables we find the expenditure of imports, domestic use, exported and generated electricity, which lost in the SNA framework due to the high level of aggregation. Also Table 5-7 harbour information on the supply of electricity which is otherwise unknown using the SNA. Like the TSA framework, with the ElSA framework we can determine several key aggregates on the electricity generation sectors such as domestic internal electricity expenditure of $1.6 Billion (Table 2), exported expenditure of £592 million, taxes less subsidies on generation of - £422.9 million (Table 6) and electricity generation GVA of £1.36 Billion (Table 5).

As well as the ElSA framework allowing for an improved understanding of the electricity sector within the SNA there is a possibility to extend the framework for other external uses. In in the context of the SNA framework – the results from the ElSA framework may be used in the disaggregation of the electricity sector within IO accounts, which is the focus of Chapter 3. The ElSA demonstrates that electricity generated will be consumed by different parts of the economy. However, the generators do not sell the electricity directly, instead they sell to a non-generator sector (i.e utilities) which then sell to consumers – a fact we can use in using the ElSA to disaggregate the electricity sector within IO accounts.

Chapter 3 – Disaggregating the electricity sector within IO accounts using ElSA

3.1 Introduction

In Chapter 2 of this thesis the concept of the SNA framework was (briefly) introduced, for which Input-Output (IO) tables are a core pillar. These accounts, explained in detail in Section 2.2, are extensively used within the field of applied economics. They are used as the basis for IO models or as the foundation in the development of a Social Accounting Matrix (SAM), the fundamental input into Computable General Equilibrium (CGE) models (Burfisher, 2010).

With one of the major outputs of this thesis being to evaluate the potential economic impacts of offshore wind developments in Scotland, both IO and CGE modelling methods are applied. The IO and CGE modelling methods will be based on the 2012 Scottish accounts, the same year as the Scottish ElSA. In IO accounts, the electricity sector in the Scottish IO tables is aggregated to a single sector. For the purpose of economic modelling there has been an argument that a high level of aggregation can be problematic with the introduction of an aggregation bias [47](Wolsky, 1984). It is because of this, and the fact the thesis has an overall focus on the offshore wind electricity sector, that we wish to disaggregate this electricity sector into several different sectors.

As we will see in this chapter, this disaggregation is based on the information gathered from the development of the 2012 Scottish ElSA, with a "bottom-up" approach being applied. In previous papers (e.g Gay and Proops 1993; Allan et al 2007) the electricity sector has been disaggregated using more top-down or bottom-up (detailed later) survey based methodologies which makes our approach using ElSA (Chapter 2) particularly novel. We have used bottom-up data, including variation in the electricity price, to be accounted for in the disaggregation. Other Scottish data including in this disaggregation is for a bottom up approach to be taken

[47] This bias is explained in section 2.3.1.

for OPEX, fuels and subsidies as there is a large variation in these by technology. The contribution of is chapter is that, by using the Scottish ElSA, we account for the variation in electricity price in our disaggregation which has been noted as being problematic in previous disaggregations (Jones et al, 2010; Algrain et al, 2014).

The next section of this chapter (3.2) outlines the principles of IO tables with explanation of the Scottish IO tables. Section 3.3 examines the literature of previous methods used to disaggregation the electricity sector in IO tables. We then give our reasoning for using the ElSA data for disaggregation in section 3.4, with the implementation of the method in section 3.5. Finally in section 3.6 the conclusions are given. This chapter details the development of the core economic database which is used in the IO and CGE modelling to determine the economic impacts of Scottish offshore wind – which is the subsequent focus of Chapter 4 and 5.

3.2 Description of IO Tables

This section will give an overview on the basic principles of IO tables explaining the Scottish IO tables used for this thesis.

IO tables are part of the SNA framework and in their simplest form are a set of economic accounts which record the inter-industrial sales and purchases within an economy. The fundamental concept of IO accounts is that every sale must have a buyer and every purchase is the result of a sale, known as double entry bookkeeping (Miller and Blair, 2009). Tables give an overview of the economy within a region or nation for a set period of time (normally a year) and represent the monetary value of all these transactions. It is common for these tables to be published on a regular basis, albeit with a delay due to data acquisition constraints[48].

IO tables are central to the SNA framework. There are different variants of these tables with the most commonly found being the 'supply-use' tables, illustrated in Tables 3.1 and 3.2.

[48] The Scottish 2014 tables were published in mid-2017, for instance. UK tables are less regular than the Scottish tables with the available being 2013 (but only partial tables with no analytical IxI table) and before that was 2010.

Table 3.1 Illustration of 'use' IO table.

		Industry		Final demand for products **(e)**	Total product output **(q)**
		1	2		
Product	1				
	2				
Value Added (v')					
Industry output (x')					

Source: Miller and Blair (2009, Chp5)

This table records the use of products (rows) by industries (columns) in the development of their products. It is in the form of products by industry (Px I) and allows for the fact that it is possible for an industry to produce more than one product. The blue covered box within Table 3.1 is known as the use matrix **U**.

Table 3.2 Illustration of 'make' IO table.

		Products		Total industry output **(x)**
		1	2	
Industries	1			
	2			
Total Product output (q')				

Source: Miller and Blair (2009, Chp5)

Table 3.2 is in the industry by product (IxP) format and records the value of each product produced by each industry. The blue covered box is the make matrix **V**.

In these 'make-use' tables with the format being in PxI or IxP they are asymmetric and unable to be used in the Leontief analysis (Horrowitz and Planting, 2009). To overcome this problem, by making assumptions these 'make-use' table can be used to generate symmetric IO tables for use in Leontief analysis. Listed below are the type of symmetric tables which are used in Leontief, along with the assumptions commonly used in their development (Eurostat, 2008)[49].

- Industry Technology Assumption (ITA) – Industries produce products with the same input structure
- Product Technology Assumption (PTA) – Products have the same input structure in any industry it is produced

Industry by Industry tables (IxI)

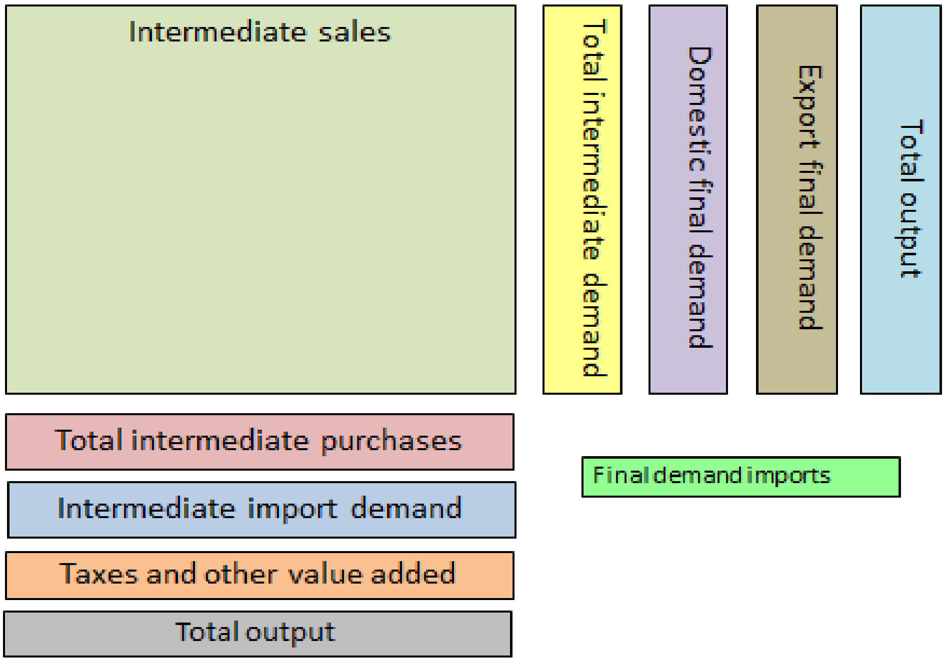
- Fixed Industry Sales Structure (FISS) - Each industry has its own specific sales structure independent of the product mix.
- Fixed Product Sales Structure (FISS) – Each products has a specific sales structure irrespective of where it produced.

The 2012 Scottish IxI matrix (developed using a Fixed Industry Sales Structure) was used for the economic modelling of offshore wind and as such this table type will be the focus of rest of this chapter (the Scottish table is detailed in the next section).

The standard IxI table is in monetary terms and can be split into 4 distinct quadrants illustrated in Figure 3.1 below.

[49] A full explanation of these approaches can be found in Appendix 2A of McIntyre (2012).

Figure 3.1: Schematic of IxI Table.



Source: Adapted from McIntyre (2012)

The upper left hand quadrant of the IO schematic records intermediate sales; i.e all the inter-industry sales and purchases within the economy. Is an n x n[50] matrix with rows representing sales of goods and services to other sectors (or self-sales) and the columns being the input purchases by each industry. This allows for the sectoral linkages to be easily identified. These industrial sectors are usually linked to the Standard Industrial Classification (SIC) coding (Eurostat, 2008b) but depending on the data available can be aggregated[51]. Totalling the row for each industry within the quadrant gives the intermediate sales for each sector with the column sales being total intermediate purchases by each industry.

As well as the intermediate economy, industries will sell output to other consumers (such as households, exports etc). This information is contained within the final demand quadrant (top right of Figure 3.1). This final demand quadrant contains the main components of GDP (production method) calculations including domestic final demand and export final demand,

[50] Where n is the number of sectors.
[51] This aggregation can lead to problems and will be dealt with in section 3.3.1.

both which can be split further depending on the data available, e.g households, governments, non-residents etc.

The value added quadrant (bottom left) shows the inputs purchased by an industry from out with the industries within the economy. As with final demand, the value added quadrant can (in separate rows) be separated into a series of activities. To generate an output (along with materials) sectors rely on labour, which incurs a cost. These costs are contained within the compensation of employees row found within the value added quadrant.

Also, it is unlikely that a region's economy will be able to supply every good needed for each industry and as such some industries may need to import goods or services from outwith the region i.e imports, which is another activity within the value added quadrant. Finally there will be taxes paid by each industry, which are represented within the value added as they are outwith intermediate purchases. The combination of the taxes, imports and compensation of employees plus other value added[52] not identified will give the total value added.

With the fundamental concept of the IO tables being that every sale must have a purchaser then the IO tables must 'balance', so that each sector's outputs must exactly equal that sector's inputs. From Figure 3.1 for each industry, the sum of sales of intermediate inputs plus the final demand for that industry (i.e. all elements in the j^{th} row of the IO table) will balance the sum of intermediate plus primary inputs (all elements in the j^{th} column of the IO table).

3.2.1 Scottish IO table

For the purpose of the empirical economic analysis within this thesis it is the 2012 Scotland IO tables which are used. The Scottish IO tables are constructed annually by the Scottish Government[53]. The development of the Scotland IxI IO table can be split into 5 fundamental stages (Scottish Government, 2011b):

[52] Including in this are subsidies and gross operating surplus and taxes on both products and production
[53] http://www.gov.scot/Topics/Statistics/Browse/Economy/Input-Output/Downloads

1. Compilation of initial supply use tables
2. Constraining column totals by industry
3. Estimation of the remainder (valuation and imports) of supply table
4. Balancing of tables
5. Conversion to IxI table

As we have the ambition to disaggregate the electricity sector within the Scottish IO accounts, it is useful to examine in detail the process that was followed to create these economic accounts.

For the development of the initial supply-use tables a variety of data sources are used by the Scottish Government including, but not limited to: Annual business survey (ABS), Products of European Community Survey (PRODCOM), UK supply tables and ONS regional accounts.

To convert the final supply-use tables to IxI the Scottish Government apply a Fixed Product Sales Structure Assumption (FPSS) whereby the sales structure of a product is fixed and independent of the industry it is produced by.

We saw in Figure 3.1 that there are several distinct quadrants in the IxI framework, for the 2012 Scottish table 98 different industries are represented within the intermediate quadrant. The final demand quadrant within the Scottish IxI tables is much more disaggregated than that identified in Figure 3.1. In the place of domestic final demand there are four columns representing households, non-profit institutions servicing household (NPISH) -which includes universities, charities, trade unions, government (both local and central) and investments (gross capital formation and valuables). As the Scottish economy is inherently connected to the rest of the UK economy this has to be identified in the IO accounts. Instead of a single column, the exports in the Scottish IxI are disaggregated into exports to the rest of the UK and exports to the rest of world as well as sales to non-residents (tourists).

As with the final demand quadrant, the value added quadrant within the Scottish IxI table is much more disaggregated than previously identified in the generic table found in Figure 3.1.

Similar to exports, the imports row is separated into imports from the rest of the UK and imports from the rest of the world. The taxes row of value added has also been split into two with one row representing taxes and subsidies on products and the other the taxes and subsidies on production. In the Scottish IxI table there is also a row for compensation of employees and gross operating surplus.

3.3 Literature review of electricity sector disaggregation

3.3.1 The Aggregation problem

In the introduction to this chapter it was identified that there is an inherent problem with the development of IO accounts, commonly known as aggregation bias (Theil, 1957). For the development of IO accounts the number of industrial sectors must be decided, which will require some degree of aggregation depending on a number factors including (but not limited to) computational expense and data availability (Miller and Blair, Chp 4).

Aggregating sectors of the economy (sectors of the IO database) reduces the size of the IO databases thus changing; the input coefficients and intermediate demand in turn, introducing an error into final calculations – which is the aggregation bias (Kymm, 1990). Commonly this aggregation bias is measured by calculating the difference between the total outputs of the aggregated system model and the un-aggregated systems model (Morimoto, 1970).

This aggregation problem has been well document since the development of IO accounts with much research carried out in the 1950s. Two key papers from this era which describe mathematical the process and problems with aggregation are McManus (1956) and Ara (1959).

While there has been well know mathematical proof of the problem, Allan et at (2007) has a particular focus on the aggregation problem with regards to the electricity sector. The authors disaggregate the original electricity sector from the 2000 Scottish IxI table in to 9 sectors (including 8 generation sectors and a non-generation sector). This allows for the calculation and contrast of the Type 1 and 2 multipliers[54]. In the paper the authors disaggregate the electricity sector using a combination of the share (in volume) of total electricity generation for each technology and survey techniques. Using shares, for example if a technology was responsible for 10% of total generation then 10% of the electricity inputs are related to this sector. Whereas, surveys can determine exact inputs for each sector – but these are more difficult to carry out.

With there being a large variation in multipliers, for electricity impacts assessments (as we carry out in later chapters), it is advantageous for a disaggregation to be carried out. Section 3.3.2 gives an overview of the methods used previously to disaggregate the electricity sector within IO accounts.

3.3.2 Disaggregation of electricity sector

There are several papers in which the disaggregation of the electricity sector within IO accounts is a key objective. Gay and Proops (1993) is one of the first – and most important due to its introduction of some commonly used key assumptions (explained below). The authors use IO techniques to investigate CO_2 emissions of a 38 sector UK economy, including three disaggregated electricity sectors where there was previously only one original electricity sector. The three sectors were identified as fossil fuel-generation, other electricity generation and electricity distribution.

For their disaggregation of the electricity sector, three central assumptions were made. First, that the two electricity producing sectors only sell to the electricity distribution sector and that sales from the original electricity sector are attributed to the distribution sector[55]. This an accurate representation of the way in which the electricity network operates (both physically and economically). Physically, all generated electricity is transported through the same system

[54] Type 1 multipliers account for direct and indirect effects and Type 2 include induce effects. These are dealt with in detail in Section 4.1

[55] In terms of the IO tables this means that all row values of the producing sectors are set to 0 apart from the sales to the electricity distribution sector. While for the distribution row all sales rows are exactly same as the original IO apart from self-sales which is calculated using $Distribution\ sales_i = Original\ sales_i - (fossile\ fuel\ sales_i + Other\ generation\ sales_i)$.

(grid) and economically the electricity is sold and bought on a series of dedicated markets. The assumption that all generation sectors sell to the distribution is the key (for the purpose of disaggregating IO tables) contribution of this paper, as it was the first to apply this method and has been used as the foundation of disaggregation throughout the literature (as will be described later in this section).

The second assumption from Gay and Proops (1993) was that fuel input (coal, gas, etc) from the original single electricity sector were assigned to the disaggregated fossil fuel generation. The third – and final - assumption was that the rest of the inputs of the aggregated of the inputs of the aggregated sector were split by the two generation sectors depending on their output. If a generation technology was responsible for 30% of total physical generation then 30% of the generation inputs were attributed to this technology. It is clear that by using a 'bottom-up" approach the ElSA disaggregation method will extend the work done by Gay and Proops (1993). Using a 'bottom up' approach allows for more accurate measurements to be made on several inputs related to electricity generation such as: fuel and O&M.

Other papers look at the disaggregation of electricity sector, include Cruz (2002) in which the authors use the assumptions identified by Gay and Proops (1993). The paper uses an extended IO methodology to investigate the energy-economy-environment interactions for Portugal, with a particular focus on the energy intensities and CO_2 emissions from fossil fuels. Initially used for the investigation was the 1992 39 sector IO table published by the National Institute of Statistics (INE), with one electricity sector. Cruz (2002) then disaggregated the electricity sector into three separate sectors: fossil fuel generation, non-fossil fuel generation (mainly hydro) and a distribution sector. As with Gay and Proops (1993) sales from the generation sectors were based on total physical output. For the inputs in the disaggregated sectors, and again as in Gay and Proops (1993), the original fuel inputs are attributed to the fossil-fuel generation and the rest are split based on generation mix. (i.e if 10% of sales were from coal then 10% of inputs of generation inputs were attributed to coal).

The assumption from Gay and Proops (1993) that all output from generation sectors will only sell to a non-generation sector, which then sells to the rest of the economy has been used throughout the literature for disaggregating the electricity sector. As identified in the previous section, Allan et al (2007) use this technique when investigating the economic impacts of different electricity generation technologies on the Scottish Economy. In that paper, the Scottish electricity sector from 2000 IO table is separated into 8 generation sectors and a non-generation sector representing electricity transmission, distribution and supply. For the sales and purchases by each of the disaggregated generation sectors the authors use a combination of top-down information and plant level surveys to produce a more accurate representation than a straight top-down methodology were only the inputs are split by generation mix. .

In the paper the authors calculate the Type 1 and Type 2 multipliers for both the disaggregated and non-disaggregated IO tables. From the results it was found that in the original IO table the electricity sector has the highest multipliers. With this disaggregation of the electricity sector the author's found that due to the large input from domestic goods, the electricity distribution sector had the highest Type 1 and Type 2 multipliers, whereas the wind sector (with low domestic goods and employment) had the lowest multipliers.

Jones et al (2010) recognize that the aggregation of the electricity sector within IO accounts limits the understanding of the electricity sector as a whole, particularly in terms of the energy trilemma and fuels used. It is because of this that the authors carried out a disaggregation of the electricity sector within the 2007 Welsh IO table.

Jones et al (2010) note that the disaggregation of the electricity sector is a complex task, while highlighting the problem of assuming an average price of electricity. As noted earlier in outlining the development of the Scottish ElSA (Chapter 2 in this thesis) each generation technology has a different principle of operation thus there is a variation in the relevant electricity price for each technology, which an overall average price of electricity does not account for. We thus are able to improve on this concern.

In Jones et al (2010) the original electricity sector is split into a non-generation sector and 5 generation sectors – coal, gas, nuclear, pumped storage and other renewables (mostly wind). In the paper the authors were able to source some plant level information on the sale of electricity to certain industries. However, this data was only available for a small number of thus the assumptions Gay and Proops (1993) was used to separate generation and non-generation sales. From the disaggregation the authors recognised that while the disaggregated IO can be used to assess the economics of electricity generation there were wider policy question which could also be answered including: assessing the reliance of the regional economy on imports; determining the effects on CO_2 emissions by varying generation mix (Jones, 2010).

Winning (2011) disaggregates the 2004 UK IO table, first by using the Annual Business Survey and generation mix (along with the assumption from Gay and Proop (1993) to disaggregate the sales of electricity by technology). Then for the disaggregation of the inputs the generation mix was used with 'reasonable' assumptions. One such assumption was to account for the O&M costs of the different technologies, while another was for the water inputs in thermal generation. As with Allan et al (2007), Winning (2011) notes that there is large variation in both Type 1 and 2 multipliers of the disaggregated electricity sectors.

The application of a disaggregated electricity sector within IO accounts has appeared in the literature for life-cycle analysis (LCA)[56] of technologies. Weidmann et al (2011) disaggregates the electricity sector within a two regional IO model into 11 sub-sectors – two for trade and transmission and nine for generation – with a focus on wind energy. For this disaggregation the Annual Business Survey is used for the sales of electricity along with the generation mix of each technology in similar fashion to the papers above.

In Liu et al (2012) investigation is made into the LCA of the electricity generation sector in Taiwan and for the analysis the authors disaggregate several sectors within the IO table, with one such being electricity. In the standard Taiwan IO table there is an identified electricity generation sector which the authors disaggregated this into 6 different technologies. For most of the inputs the disaggregation is carried out using the proportion of each technology to overall electricity generation. However, for disaggregation of fuel inputs assumptions similar to Cruz (2002) were used. Using the disaggregated IO table the authors calculate CO_2

[56] LCA is a framework which captures the effects throughout all phases of the life of a product, services or sector. Known as 'crade to grave' the methodology starts from raw materials through to disposal and has been extensively used to investigate the environmental effects of the electricity sector. There are several different variations on the methodology for investigating the electricity sector with a common method (EIO-LCA) using IO tables.

multipliers and find that there is a large deviation in the disaggregated multipliers compared to the aggregate – ranging from -99.2% to 48.2. This again shows that it is advantageous to disaggregate the electricity sector to determine the variation in sectoral multipliers.

In the LCA literature there are methods, other than using the Gay and Proops (1993) assumption, which are used to disaggregate the electricity sector within IO account. Marriot (2007) disaggregates the use electricity sector within the US IO tables into 6 generation technologies. Instead of using the assumption of Gay and Proops (1993) the author uses state level generation mixes and assume electricity consumption by sector is based on the number of employees. This allows for estimation to be made for the sales of electricity by technology (rows of IO) to each sector (by state), which was aggregated to a national level. The authors use bottom-u data to calculate the value of the supply chain (O&M, fuel, etc) of the six technologies. In a similar fashion to that found in Marriot (2007), Algarin (2014) uses US state and federal electricity production figures and manual assumptions to disaggregate the electricity sector into 10 generation technologies.

3.4 Advantages of using the ElSA methodology

The previous section described in detail that there have already been several methods used to disaggregate the electricity sector with IO accounts. However for all the methods described there remains a fundamental problem in that it is assumed that the electricity price remains constant, as identified by Jones et al (2010) and Algarin et al (2014). Many of the papers above – based on Gay and Proops (1993) – assume that the sales by generation technology are split based on their share of total electricity generation.

However, in the previous chapter it was demonstrated that these generation technologies have different roles within the electricity system thus affecting the electricity price[57], but to date this has not been incorporated into a disaggregation of the IO accounts. Instead of basing the disaggregation on each technologies chare of total electricity generation, our disaggregation is based on the total value of generation by each technology, which inherently takes into account

[57] This is explained further in Table 2.20 of this thesis.

variations in the price of electricity and the time pattern of operation of the different generation technologies.

Also in the literature above much of the disaggregation is carried out using a top-down method or by use of surveys. In Cruz (2002) most of the inputs, other than fuel, are based on the generation mix of electricity. Thus for example if coal was responsible for 40% of the total generation then 40% of the generation inputs are attributed to the disaggregated coal sector. This will not be the most accurate of techniques but it does have the advantage of being convenient and pragmatic, particular without any other data. Allan et al (2007), on the other hand, use surveys to identify the disaggregated inputs. This technique while accurate – in determining the supply chains of the different technologies - can be quite difficult to apply due to time and confidentiality constraints. The proposed bottom-up approach of utilizing data from the ElSA model, based on publically available data, allows for a more accurate disaggregation than "full top-down" method while being quicker and easier to carry out than the survey method. We describe our proposed method in the next section.

3.5 Disaggregating the electricity sector within IO accounts using ElSA data

The section below outlines the method carried out to disaggregate the original electricity sector within the 2012 Scottish IO table into a single non-generation sector and 7 generation sectors. The generation sectors included are: coal, gas, nuclear, hydro (both flow and pumped storage), onshore wind and offshore wind and other. Six of these generation sectors (all except offshore wind) were chosen as they come directly from the ElSA development. In the ElSA framework there is only a single wind sector but as this IO table is to be used for economic modelling of the Scottish offshore wind sector this was further disaggregated into an onshore and offshore wind sector (using Elexon and Nordpool data).

The first stage of the disaggregation was, following Gay and Proops (1993) and others, to disaggregate the electricity row by assuming that all the sales from the generation sectors are only to the non-generation electricity sector. As outlined earlier, in previous studies (e.g. Gay and Proops, 1993), it has been assumed that sales from each technology were directly related to that technologies share of generation. However, using the data from the ElSA allows variations in electricity price by technology to be taken into account. The sales of electricity from each technology were input and the residual electricity ($Output_{orginal\ elec} - \sum Output\_technology_i$)sector attributed the non-generation sector, these are recorded in Table 3.3 below.

Table 3.3: Disaggregated electricity sales.

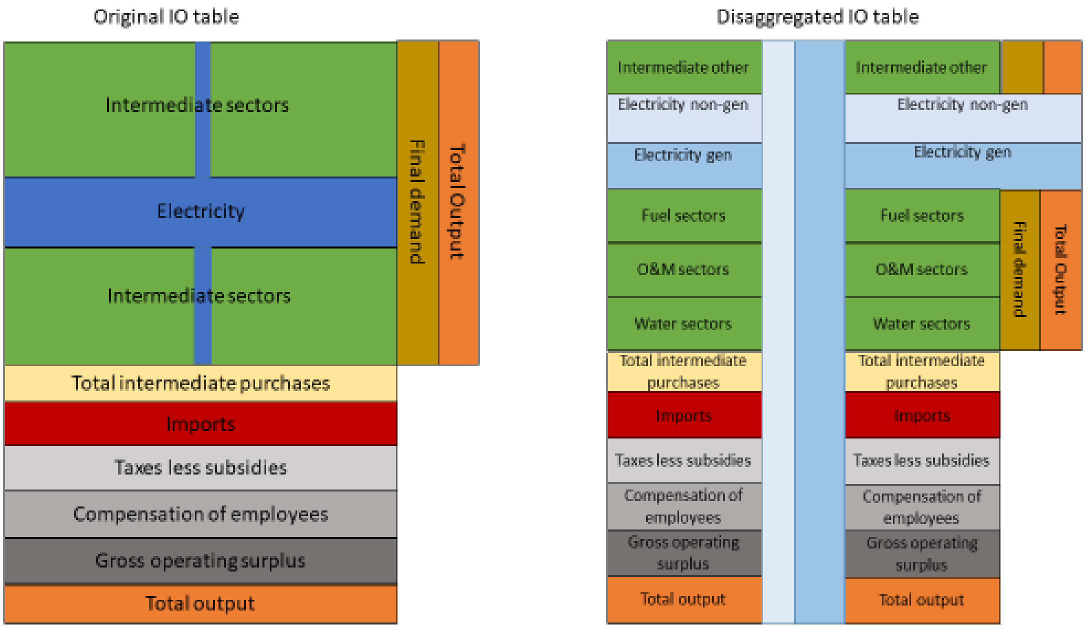
Disaggregated Sector	Total Electricity Sales (£m)
Non- Generation	5473.55
Coal	520.62
Gas	247.13
Nuclear	735.07
Hydro	242.89
Onshore Wind	338.86
Offshore Wind	22.23
Other	88.56

Source: 2012 Scottish ElSA

By construction totalling these gives £7668.88million (the output of the original aggregated electricity sector), which equals the total value of sales found in the electricity sector in the 2012 IxI table.

Whereas disaggregation of the sales that make the aggregated electricity sector (rows) was a relatively simple task using the data in the ElSA, the disaggregation of the electricity purchases (inputs) requires a much higher level of detail analysis. Combining previous methods for this input disaggregation along with the information gathered from the development of the Scottish ElSA we apply a more bottom up approach. Figure 3.3 gives an illustration of disaggregation the Scottish IO table.

Figure 3.2: Schematic of disaggregation of Scottish IO table.



Source: Author

From Figure 3.2 we find that both a rows and columns and rows are added to the IO table when we carry out a disaggregation. The electricity sales (rows) are disaggregated using the ElSA data, whereas for the columns disaggregation we use a variety of techniques. In Figure 3.2 we identify a range of non-electricity sectors (fuel, O&M) which are important in electricity generation, for which we carry out bottom-up approach to disaggregate, which is detailed in this section. However the first stage of input disaggregation was focused on the ‘intermediate other sectors’.

Fundamentally the sum of the disaggregated electricity sector inputs from each sector must equal that of the original electricity sector. As seen above, some of the literature splits the inputs into non-generation and generation sectors based on their output and then further split the generation by generation mix. This top-down method was carried out for the other sectors found in Figure 3.2.

From Table 3.3 the non-generation sector is responsible for 71.37% of all electricity sales with the 28.63% attributed to the generation sectors. The generation sectors only sell to the non-generation sectors thus there are all intra-sectoral sales, while the non-generation sectors sells this electricity to the rest of the economy. These sales percentages are used to disaggregate each split the original electricity sector into non-generation and generation, with generation being split further using the proportion of generation sales (by value) by technology. A demonstration of how this was carried out for 3 'other' sectors is found below.

For 3 'other' sectors of the original Scottish IO table the sales to (inputs) the electricity sector were as follows.

Table 3.4: Illustration of three sector sales to electricity sector.

Sector	Sales to electricity sector (£m)
Paper and paper products (PPS)	2.96
Support services for transport (SST)	11.08
Computer services (CS)	4.51

Source: 2012 Scottish ElSA

Using the information from Table 3.3 we can calculate the percentage contribution of each technology to total generation, demonstrated in Table 3.5.

Table 3.5: Scottish electricity total sales with percentage of total.

Generator	Total sales (£m)	Percentage of total sales
Coal	520.62	23.71%
Gas	247.13	11.26%
Nuclear	735.07	33.48%
Hydro	242.89	11.06%
Onshore Wind	338.86	15.44%
Offshore Wind	22.23	1.01%
Other	88.56	4.03%
Total	2195.35	100.00%

Source: Author's calculation

Using this information gives disaggregated electricity inputs of the three sectors in Table 3.4 are as follows

Table 3.6 Illustration of disaggregation of 3 ‘other sectors’

	Non-generation	Coal	Gas	Nuclear	Hydro	Wind on	Wind off	Other	Total
PPS	2.11	0.20	0.10	0.28	0.09	0.13	0.01	0.03	2.96
SST	7.91	0.75	0.36	1.06	0.35	0.49	0.03	0.13	11.08
CS	3.22	0.31	0.15	0.43	0.14	0.20	0.01	0.05	4.51
Percent of total	71.37%	6.79%	3.22%	9.59%	3.17%	4.42%	0.29%	1.15%	100%

Source: Author’s calculation

While it would be an over-simplification for this disaggregation method to be used for the all inputs of the original electricity sector, this method has been used for the inputs in which there is little information available or the value was small i.e the ‘other’ sectors from Figure 3.3. For the more important inputs to the electricity sector (i.e fuel, O&M) a much more compressive approach was taken to determine accurate input values, combining top-down and bottom-up approaches.

When electricity is being generated by fossil fuel plants (coal, gas, nuclear) there will be a fuel input, which has to be taken into account in the disaggregation. The method of using the generation mix to assign the inputs, as used before, would be inaccurate given different technologies have different use different fuels. Winning (2012) and Allan et al (2007) noted this and used top-down decisions, in the case of Allan et al (2007) assumptions, to assign the fuel inputs to the technologies[58]. An example of this is that they assumed all inputs from the coal mining sector are for the coal generation sector. This is likely to be accurate, to an extent, but in our disaggregation we go one step further and work out the fuel consumption using a

[58] Surveys were a part of this paper but were only used for some of the inputs e.g wages

bottom up approach. From the ElSA data the physical output of these fossil fuel plants is known along with average fuel price for any given year from the BEIS (2013a) data.

Scotland only had two coal fired power plants in 2012. There is information available on the exact fuel consumption (Scottish Power, 2013) for 2012 for one of them (Longannet). This gives both the coal and gas, used from start up, consumption in Tonnes and Mm^3 retrospectively which is converted into pounds[59] using the information from BEIS. While there is no similar information available for the other coal fired power station (Cockenzie) however we decided that since the two plants were of similar age – that the fuel consumption would be similar. Thus for Cockenzie, coal and gas consumption the Longannet numbers were scaled based on output. With these costs it was found that for the coal power plants in Scotland in 2012 the total cost of consumed coal was £297.62 million and gas £11.13 million. This coal consumption is much greater that the electricity inputs from coal in the original IO table of £85.44 million. As such we assumed that all of this £85.44m went to the disaggregated coal sector and the other £212.2 coal inputs were imported. The gas consumption of the coal sector is directly input as £11.13 million.

There is no such plant level information available for the other fuel types, instead assumptions were made on the conversion from fuel source to MWh for an average power plant, then converted into monetary terms using the BEIS (2013a) information. For the gas power plants in Scotland it was determined that the total value of gas consumption equates to £111.93 million. This consumption is lower that the gas inputs into the original electricity sector thus this value was directly input as the value of purchasers from the gas sector by the disaggregated gas generation sector. However, for the nuclear sector the fuel consumption was estimated to be £81.37 million which is much larger than the £1.9 million input from coke and nuclear fuel in the original IO. Because of this we applied a similar method as we did for coal fuel. £1.9 million is taken as a domestically produced input into the nuclear-generation sector then the remaining £79.47 imports from the rest of the UK, which has a large nuclear fuel industry in comparison with Scotland. It seems sensible that, as nuclear fuel is seen of national

[59] Prices were converted taking the average USD/GBP conversion rate for each month in 2012.

importance, it would actually come for the rest of the UK rather than being imported from the rest of the world – this is also in line with Allan et al (2007).

A similar approach was taken for oil and biomass technologies, which are the part of the other-generation disaggregated sector. Using information from the 2012 Scottish ElSA the total value of 'other fuel' was calculated as £30.9 million (£26 million oil and £4.6million biomass). The Scottish economy has a large oil and gas sector, but this is not represented in Scottish IO table (Scottish Government, 2011b) and as such for the disaggregated other-generated sector it is assumed that the oil fuel inputs are attributed to imports. Whereas for the biomass part of other generation sector it was assumed that the £0.56 million of agriculture inputs to the original IO are attributed to biomass fuel with the other £4.04 million of fuel coming from imports.

Similar to the fuel inputs we decided that a bottom-up approach would be applied to determine the operation and maintenance (O&M) cost for each of the technologies. For this BEIS (2012) also produce estimates for the two types of O&M costs, fixed and variable for a variety of different technologies. Fixed O&M costs detail; the costs which occur at set intervals i.e scheduled maintenance, with variable costs which deal with components breaking and needing to be fixed straight away. The associated total O&M costs are found below in Table 3.7

Table 3.7: Associated O&M generation technologies.

Generator	O&M cost (£/MWh)
Coal	6
Gas	3
Nuclear	11
Flow	23
Pumped generation	14
Wind onshore	20
Wind offshore	16
Other	6-28

Source: BEIS (2012): BVG (2012)

Table 3.7 shows found that there is large variation in the O&M costs of each technology. Overall the more mature technologies (fossil plants and pumped hydro) have a lower cost than the renewable technologies, largely due to their operating environments. The notable exception to this is offshore wind at £16 MWh. The reason for this relatively low value (compared with other renewables) is that Robin Rigg, the only offshore wind farm in Scotland operating during 2012, is a near coast farm reducing O&M cost significantly. Also with there only being one offshore wind farm in 2012 we obtain specific O&M values (BVG, 2012) Using this O&M data along with the total generation by technology allows for provides a calculation of total yearly O&M to be made using Equation 3.1.

$$Total\ O\&M\ _I(£) = Yearly\ generation_I\ (MWh) * O\&M\ cost\ _i(\frac{£}{MWH})\ (3.1)$$

Using this information the percentage contribution of each technology to the overall O&M costs was found, with the results in Table 3.8.

Table 3.8: Generators contribution to O&M.

Generator	Contribution to O&M
Coal	11.73%
Gas	2.81%
Nuclear	31.14%
Hydro	19.42%
Wind onshore	26.81%
Wind offshore	1.41%
Other	6.68%

Source: Author's calculation

From the original IO table there was assumed to be 3 sectors which represent inputs of O&M to the electricity sector: construction, wholesale – exc vehicles and repair and maintenance. In the literature there a several different methods used to disaggregate the O&M for the electricity sector. Jones et al (2010) disaggregate the O&M costs by assuming that all inputs for to the original IO from construction are attributed to the generation sectors. However, this does not account for the O&M costs in the non-generation sector (i.e on the transmission and distribution system). In Allan et al (2007) half of the construction inputs to the electricity sector were attributed to hydro with coal and nuclear a further 20% each. But this disaggregation is for 2000 were the Scottish electricity system when renewables were in it's infancy. To account for the differences in the network and the fact that there will be operating costs in the non-generation sector, in our disaggregation we assume that 50% of sales to the original electricity sector from the above 3 sectors are attributed to non-generation and the other 50% to the generation sector.

The generation sector is further split into technology by using the percentages found in Table 5.8. When doing this we found that the bottom-up calculated O&M costs are much higher than the total inputs from the 3 sectors reported in the IO tables. Thus, as with fuel costs, it was assumed that the remainder of the O&M inputs are associated with imports.

In Allan et al (2007) the authors take account of the water usage from nuclear plants by disaggregating the water inputs from the original aggregate sector, with 90% attributed to the non-generation and other 10% to the nuclear sector. The same approach is taken in our analysis.

Previously, when disaggregating the 'taxes less subsidies' on products element of the electricity sectors the generation mix has been used. Winning (2012) argued that with the introduction of ROCs etc it would be advantageous for this to be separated differently, which we are now able to do using the ElSA information. For this we used the information from Table 6 of the Scottish ElSA. When doing this we found – due to the ROC scheme being in place to promote renewables - that subsidies for the renewable sectors are large compared to carbon taxes and as such it means that the tax-subsidy input for the disaggregated non-generation sector is much higher (£590.6 million) than that for the original taxes on products from the electricity sector (£167.7million).

The other two value added sectors which disaggregated (as found in Figure3.3) were the compensation of employees and gross operating surplus. The compensation of employees is the payments made by the sector to the employees' i.e wages. For the disaggregation of this, information was used on the employment by the different generation technologies from Table 7 of the Scottish along with average wage information from the 2012 Scottish IO table. The gross operating surplus entry was used as a balancing item ensuring that sectoral inputs equal outputs.

3.5.1 Key features of the disaggregated table

A version of the disaggregated electricity sector within a 23x23 economy – used for the IO modelling – can be found in Appendix 3A. Some key features of the disaggregated electricity sector will be discussed in this section.

One important characteristic from IO accounts is the value of inputs (compared with output) which are sourced from the other sectors in the region i.e intermediate goods. The higher the proportion of intermediate goods the greater effect an increase of output will have on the economy[60]. From the disaggregated IO table we found that the 3 electricity sectors with the highest share of intermediate goods are; non-generation activities (56.2%), gas generation (49%) and coal generation (23%)[61]. Through the use of the Gay and Proops (1993) assumption the non-generation sector within the disaggregated IO table acts as the distributer of electricity between the generators and the consumers thus a large proportion of these intermediate inputs. For gas and coal generation a large contributor to their intermediate goods is the fuel used for generation.

Other than the intermediate goods the proportion of the compensation of employees compared with output is another key variable when investigating IO accounts[62]. Overall the Scottish

[60] This is the basis of Type 1 multipliers which are explained in detail in Chapter 4.
[61] Comparing these results with the Allan et al (2007) we find that for gas consumption these results for intermediate input are similar (44.5%). However, there is a notable difference in the coal intermediate input ratio using our method 23% compared with the estimate in Allan et al (2007) of 46.9%. This occurs because we have calculated the bottom up fuel consumption which needs a high level of imports
[62] These are important for the Type 2 multipliers, again explained in Chapter 4

electricity sector is not labour intensive, from the original 2012 Scottish IO only 6.91% of the value of inputs is attributed to compensation of employees compared with 30.36% for the economy as a whole. This is replicated for most of the disaggregated electricity industries where COE accounts for less than 10% of total inputs. The one outlier is offshore wind with a compensation for employees ratio of 48.63%. This occurs because, while the output of the offshore wind sector was low in 2012, there was still a high number of employees in this generation sector (>100).

3.6 Conclusions

The disaggregation of the electricity sector within IO accounts is not a new endeavour; it has been carried out several times in the past for a variety of different reasons. Gay and Proops (1993) laid the fundamentals of disaggregation of the electricity sector, where the main assumption is that all generation sectors output must be sold to a single non-generation sector. A number of studies which use the Gay and Proops (1993) approach and assumes that the output of each generation technology was found by taking that technologies share of total physical generation.

The Gay and Proops (1993) assumption does not take into account variation in the electricity price and the principle of operations of the different technologies. When using the physical output of generators for a disaggregation the assumption is made that the yearly average cost of each generation technology is the same, Table 2.20 of this thesis shows that this is not the case and also Jones et al (2010) indicates that the use of an average price of electricity can be problematic. In our disaggregation of the sales of the electricity sector by technology we use the information gathered from the 2012 Scottish, which due to the nature of construction takes into account the variation in electricity price. This is the first contribution of this chapter.

As well as the outputs, the inputs of the electricity sector must be disaggregated. Previously there has been two main methods carried out to achieved this, a bottom-up survey method (which is accurate but time consuming/costly) or a top-down method using the generation mix with assumptions (fast but not as accurate). In this chapter the input disaggregation described is a hybrid approach combining parts of the top-down method with that of the bottom-up approach using information from publically available sources and the information provided by the ElSA of Chapter 2.

Previously when a top down methodology has been applied (Cruz, 2002; Liu, 2012) the author's separate the inputs to the electricity for most sector by share of total generation, while using some assumptions on the fuel inputs (i.e all coal production is to coal generation). While with a survey method, planet level data is acquired which allows for the creation of a supply chain per technology.

In our Hybrid approach for sectors which do not have a large input to the electricity sector (i.e education etc) we disaggregated using the same methodology as a full top-down methodology – based on the shares of total output by value. However for more important sectors, such as fuel and O&M the inputs are calculated using publically available sources. While it is recognised that this methodology will not be as accurate a full bottom-up approach, it is easier and faster to implement while improving upon the top-down methodology. This hybrid approach of disaggregating inputs is the second contribution to research from this chapter.

In the next chapter we use the disaggregated IO table for IO modelling and analysis. We also investigate the effects on sectoral multipliers of using this disaggregated IO table.

Part B – Economic impacts of increasing Scottish offshore wind capacity

In part A of this thesis the focus was on the representation of the electricity sector within economic accounts and how this can feed into economic models. In Part B the focus shifts to an assessment of the economic impacts resulting for increases in Scottish offshore wind capacity. The introduction of this thesis noted that there is huge potential for offshore wind in Scotland – with 25% of all European wind energy resource (Scottish Government, 2011a). Due to increased ambition in renewable energy technologies, and the decreasing cost of wind generation, there are plans to dramatically increase the installed capacity of offshore wind in Scotland in the near future (Renewables UK, 2017a). This development will not only affect the electricity mix in Scotland but will generate economy-wide impacts.

An increase in offshore wind will result in an increase spending on construction and O&M in Scotland. In the two chapters of this section we measure the economy-wide impacts using two methodologies – IO and CGE. IO has been used extensively in the literature to measure the economic impacts of renewables and as such we use this in Chapter 4 to measure the impacts of increasing Scottish offshore wind capacity output, GVA and employment. However, IO has several assumptions (such as passive supply side and fixed price) which we relax in Chapter 5 through the use of a CGE model. In both Chapters 4 and 5 a range of scenarios are modelled along with changes in local content.

Chapter 4 – Input-Output modelling of increasing offshore capacity

4.1 Introduction

There is a large literature using Input-Output (IO) models to determine the economic impacts of renewable projects (e.g FAI, 2017) on which this chapter builds. The next chapter examines the economic impacts are further investigated through the use of CGE models, which has never been done before to understand the economic impacts of offshore wind developments in Scotland.

Chapter 3 introduced the concept of IO tables which give the monetary flow of the economy in a given year and linkages between different production and consumption sectors in an economy. As well as than being used as an accounting framework, IO tables are used extensively as the primary inputs to demand-driven IO models (Miller and Blair, 2009). Within the tables, the sectoral sales and purchasers of goods and services from other sectors are identified – showing the links between sectors (i.e the 'supply chain' for inputs to each sector). Changes in the demand for output of one sector will have an effect on other sectors of the economy. This is the basic principle behind demand-driven IO modelling, introducing an external demand shock and determining the effects on the whole economy. As the IO tables are multi-sectoral, these also show how the shock impacts on different sectors in the economy.

While economic impact assessments have been carried out for individual offshore wind projects in Scotland using IO (e.g Beatrice offshore windfarm Ltd, 2017; FAI, 2017) this chapter is the first analysis – to the authors knowledge – of the cumulative effects of all planned capacity in Scotland.

Also, this chapter builds on the previous work by investigating not only the overall effects but also investigates the sectoral effects, and the timing of these effects (these are more the focus of Chapter 5 but some results are calculated using IO).The final contribution to the literature of this chapter is that by using a IO table/model with electricity disaggregation as in Chapter

3, we have a model where the disaggregation of the electricity sector accounts for variation in the electricity price

Finally, in this chapter we investigate the effect of increasing the scale of the local supply for offshore wind (through varying the share of local content) and see how this impacts upon our results.

This chapter proceeds as follows: Section 4.2 is a literature review of regional development and IO models with renewables Section 4.3.introduces the concept of local content and why it is important for the assessment of economic impacts and offshore wind. The IO methodology is given in Section 4.4. Section 4.5 details the modelling demand shocks. The results and discussion of the economic impacts of Scottish offshore wind developments given in Section 4.6 with the chapter concluding in Section 4.7

4.2 Literature review

4.2.1 Renewables and regional development

In this thesis we are investigating the regional impacts of offshore wind capital investment in Scotland. Most economic impacts assessment focus on national impacts, however it is important to also identify the regional impacts. .In this section we review some of the literature which focuses on renewables and regional development[63].

Jenniches (2018) is a comprehensive literature review of renewable energy developments and regional economic impacts. The authors state that focusing on regional developments is beneficial for one key reason - the planning decision for renewable energy projects is often taken at a regional level, thus it is important for these decision makers to know the economic impacts to the region. The author analyses a set of 54 publications from: the UK, USA, Spain, Germany and Austria and find that regional economic impacts of wind energy are the most common type of paper. In the review 4 fundamental methodologies which measure regional

[63] Several of the papers detailed in Sections 4.42 and 5.2.3 also deal with regional economic benefits of renewable

economic sbenefits of renewable energy sources are identified: employment ratios; supply chain analysis; IO and CGE modelling.

In Sastresa et al (2009) the author's use a novel employment factor methodology to measure the regional economic impacts of renewables in the autonomous Aragon region of Spain. As mentioned above two widely used methodologies for economic impact assessments are IO and CGE models[64], both of which rely on information from IO tables. Many regions do not have separate IO tables making impact assessments difficult, thus the authors develop their employment factor method. The method uses surveyed data on 5 key regional energy indicators: territorial situation; technology; business structure; training supply and professional structure to develop the renewable employment ratios. With these ratios the authors calculate the jobs/MW ratio for 3 renewable technologies (wind, thermal solar; PV) in Aragon, which can then be used in impact assessments.

Fanning et al (2014) investigate the employment returns from wave and tidal energy in Wales. The author's note that while local social economic benefits are not chief aim in national/multinational renewable policy, they are important to for policy makers to understand claims of firms. An IO methodology, to capture system wide impacts, is applied in the paper with 3 scenarios modelled (60MW, 300MW, 1GW). As to expected there would be an increase in employment in all three scenario ranging from between 2,080 and 24,200 FTEs. With IO modelling being multi-sectoral, the authors conclude that much of the regional employment would be in the manufacturing/energy and construction sectors.

Two papers which investigate potential biomass economic impacts on a regional scale are Allan (2013) and Madlener and Koller (2007). Allan (2013) reviews the potential for both IO and CGE models to investigate the regional economic impacts of biomass. Whereas Madlener and Koller (2007) use an IO methodology in the measurement of both economic and CO_2 impacts of promoting biomass in the Vorarlberg region of Austria.

[64] These methodologies are described in detail later in this thesis.

4.2.2 IO modelling as a tool for economic impacts of renewables

IO modelling is the most widely used technique to determine the economic impact. With a primary output of this thesis being the results from IO economic modelling of the potential impact of offshore wind capacity in Scotland, this literature review will pay particular attention to the use of IO modelling for renewable energy systems (especially wind).

The work in this thesis for the IO offshore wind simulations for Scotland will be similar to the reports above with the creation of different scenarios with varying installed capacity and local content. To date there has been no evaluation of the economic impacts of an overall increase in wind energy capacity in Scotland, which is a contribution of this chapter. There are however individual project level economic assessments for Scottish offshore wind projects – e.g Beatrice (Beatrice offshore windfarm Ltd, 2017; FAI, 2017). We later compare the results from these report with that of our IO model.

As set out in Chapter 1, by the beginning of 2017 the UK was the world leader in offshore wind energy with more than 5.1 GW (Wind Europe, 2017) of installed capacity. With the offshore wind sector being of such high importance there have been studies carried out to determine its potential economic impact ORE (e.g Catapult (2014) and CEBR (2012)) – both of which are based on IO techniques. In the ORE Catapult method, simulations were carried out for four different scenarios (8GW gradual growth, 15GW gradual growth, 8GW accelerated growth and 15GW accelerated growth) with a range of outputs for several variables – production, GVA and employment – given. These scenarios are based on projection of the growth in capacity of UK offshore wind taken from a variety of source. In the results it was estimated that by 2020 there is the potential of between 11,383 and 34,870 FTE jobs and a potential direct GVA impact up to £1.6 Billion. Aura (2017) published report in which they estimate – through an IO methodology – that the offshore wind development in the UK could lead to an increase in employment of 60,000 FTEs.

CEBR again use IO techniques to determine the economic impact of UK offshore wind. In this report particular attention is paid to the local content of UK offshore wind, in the report there are 9 different scenarios modelled. Results ranged from 26,863 FTE and £1,282 million GVA by 2030 in the slow progress scenario to 71,799 FTE and £3,390 million for the accelerated scenario. In the report the scenarios are based on estimates on future potential MW per years as well as local content – similar to we carry out. One particular point of this report which stands out from others is that there is investigation made into the potential economic impacts resulting from exporting components and Expertise to other worldwide offshore windfarms.

As has been identified earlier IO modelling has been used extensively for a variety of different technologies. Allan et al (2014a) use both IO and CGE modelling to investigate the potential economic impacts an increase in Scottish marine energy (wave and tidal) on the Scottish economy. In this paper the authors allocate categories of spending in the development of these technologies to industrial SIC codes for use as the demand shock in modelling. This is a similar approach to that used in this paper were we match the various costs of offshore wind with SIC sectors.

The National Renewable Energy Laboratory (NERL) has developed several Jobs and Economic Development Impact (JEDI) IO models to determine the economic impacts of projects within the USA. In these JEDI models a profile of investment spending (the demand shock) is estimated and the IO tables are based on the state in which project is being developed (Goldberg & Milligan, 2004). With the large variation in nature of the applications of this model, there is a large literature using these JEDI models. For example. Tegan et al (2015) investigate the economic impact of offshore wind in four regions of the USA – Mid Atlantic; Great Lakes; Gulf of Mexico and the Southeast – using the offshore JEDI model. For each region a deployment scenario was developed with associated costs. In a similar fashion to the offshore JEDI, the onshore JEDI model has been used extensively for the analysis of the economic impacts of onshore wind developments for different regions within the USA (Reategui and Tegan, (2008), Slattery et al, (2011)[65].

Other than JEDI there are other assessments on wind for regions/countries world-wide including, Welsh Economic Research Unit (WERU) (2013). In this paper estimation are made into the potential economic impacts arising from onshore wind developments in Wales until

[65] Both the on-shore and off-shore wind are based on the principles of IO, with the differences being in the demand shocks as the expenditure of an on-shore wind farm is different to that for an off-shore

2025. For the modelling the authors use estimates of expenditure at each stage of the life span of a windfarm with particular attention paid to the expenditure kept within Wales. To aid in the estimations of this local content surveys were used. Using surveys is a common method to determine costing/demand shocks although they can be difficult to implement as at times the data is sensitive and confidentiality issues arise[66]. Other than wind energy, there have been several other studies carried out using IO to determine the economic impacts of renewables in Wales including Fanning et al (2014) and Bere et al (2015) which look at wave/tidal and small hydro in Wales retrospectively. In both Fanning et al (204) and Bere et al (2015) the author' have estimated the expenditure of the given project by stage, with attention paid to the expenditure within Wales – a method in which we follow in the modelling of Scottish offshore wind energy.

In Blanco et al (2009) the authors give a review of reports/papers where there has been estimates made of employment supported by the wind generation sector in Europe, within which there are papers which use an IO framework. Again illustrating the methodologies usefulness.

There are many examples of IO modelling being used to determine the macroeconomic impacts resulting from renewables. In Markaki et al (2013) the authors first estimate the 'green' investment (e.g renewables) need for Greece to meet several energy and environmental targets, mainly the EU2020 targets. With this green investment identified the authors then introduce this investment as expenditures in an IO model to determine the macroeconomic impacts resulting from such investment. Again focusing on Greece, Mirasgedis (2014) investigates the employment impacts from utilising renewable energy through the use of an IO framework. In this Mirasgedis (2014) paper the author notes the impacts of local content with investigation made into the impacts of using domestically used equipment compared with imported. This is a concept that we explore in this chapter by analysis the impacts of varying local content.

[66] This was a problem encountered with this thesis as exact spending and local content data is difficult to source for planned offshore wind farms due to the sensitivity and commercially confidently of data.

The above literature indicates that the IO modelling is a highly regarded and relevant methodology for measuring economic impacts of wind (or renewables) projects. Some advantages of IO include: the transparency of the method and the easy of identification of results, both in aggregate and sectoral. With this justification the methodology was felt appropriate to apply for Scottish offshore wind.

In the modelling of renewable projects, the above papers have applied a methodology were by there is a series of demand shocks based on the expenditures of the projects. The author's calculate expenditure at various stages of the project with attention paid to the local content. This is the methodology we apply in this thesis, with the next section detailing how we developed the shocks.

4.3 Local content and Scottish offshore wind

Identified in the introduction, one of the contributions of this chapter is to investigate the economic impacts of changes in local content of Scottish offshore wind farms – which drives regional impacts. Local content is the expenditure of a project within the region of focus and is important for economic impact assessments as a higher level of local content implies greater economic benefits.

While there may be economy wide benefits of increasing local content for offshore wind projects it is unrealistic for 100% local content for projects, as this would reduce competitiveness and increase overall projects costs. It is because of this that there has been much debate by UK and Scottish policy makers on the 'ideal' level of local content for offshore wind projects and how this may be achieved. There are several policy measures which can be implemented to support an increase in local content including: local content requirements; financial/tax incentives and favourable customs duties (Lewis and Wiser, 2007).

With the UK having a large and diverse economy, as well as a large installed wind capacity, the local content target is substantial – set at 50%. This is not a target set by the government, but rather the developers themselves as according to Kern et at (2014) "may be a struggle for offshore wind to survive politically if it doesn't increase its UK local content". As is detailed in Section 4.2.2 current UK offshore wind projects are on course to meet these targets, with former energy minister Michael Fallon leading a recent report calling for the UK local content target to be increased to 60% for projects delivered up to 2025[67].

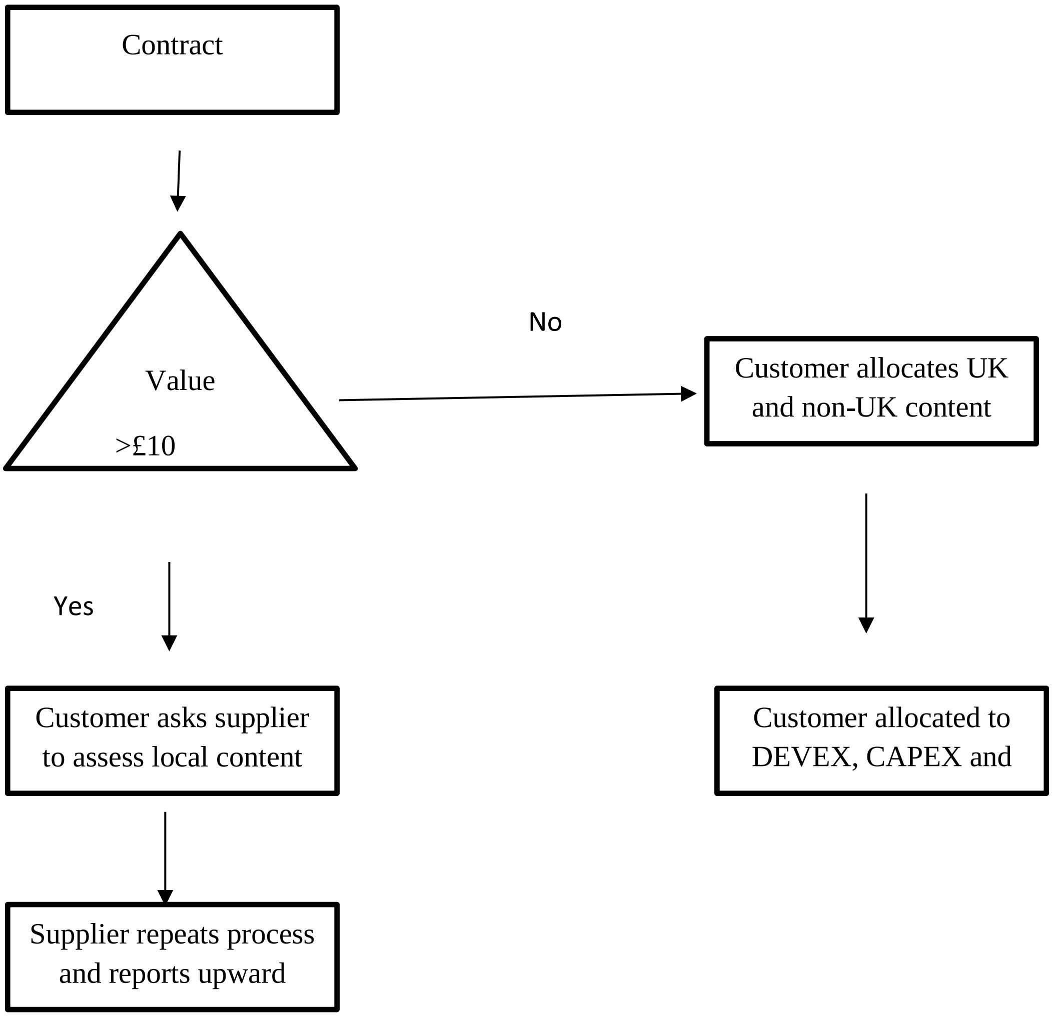
As with the UK Government, there is no hard targets being set by the Scottish Government on the level of local content. Scotland has a much smaller economy that the UK as whole indicating that the local content will be lower, with the Scottish expenditure focused on a select few offshore wind stages – such as planning, installation and electrical components. Even though there are no Governmental targets there has been some indication that local content is a key determinant used when awarding planning permission to offshore wind developers (Crown Estate Scotland, 2018).

4.3.1 Measuring local content

The local content share of project expenditure is important in determining the local economic benefit of that project. For offshore wind in Scotland there is no predefined methodology for measuring the local content, there is however a method developed by BVG Associates (2015) to calculate local content for the UK a whole. While this was not developed specifically for Scotland this method could be adapted for Scotland. The BVG (2015) method was developed to standardise the method of calculating local content shares and should be carried out by the offshore asset owners as they lead the project and have insight from all suppliers. An illustration of the method is found below in Figure 4.1.

[67] https://www.offshorewind.biz/2018/04/20/report-recommends-uk-content-increase-in-offshore-wind/

Figure 4.1: Schematic of UK local content methodology.



Source: BVG (2015)

With this methodology a filtering system is applied with each contract being investigated individually. The start of the process beings with the large tier 1 contracts[68], if the contract is valued greater than £10 million (which they will most likely be) then the responsibility of measuring local content falls on the tier 1 suppliers who then report back to the asset owner. At this stage the tier 1 suppliers investigate the sub-contracts (tier 1) and for any project above the £10 million threshold the responsibility of local content measure is allocated to the tier 2 supplier. Whereas for any contract under the threshold it is the responsibility of the tier 1

[68] Tier 1 contracts are the contracts for the major components of offshore wind farms –turbines, substations, foundations and cables.

supplier to estimate the percentage of local content in the contract. This process is repeated through the supply chain until the value of all sub contracts are less than the threshold. When estimating the local content the following principles are considered.

- Any information provided by the supplier
- The invoice address of the supplier
- The currency in which the payment was made
- The customer's knowledge of its suppliers activates and sub suppliers

BGV recommends the methodology should be carried out within a year of the final investment decision being made and it is the responsibility of the asset owner to report of the local content of the DEVEX, CAPEX, OPEX and TOTEX.

4.3.2 Local content of current UK and Scottish offshore wind farms

With there being a much higher installed capacity of offshore wind in the UK as a whole compared with Scotland; the information available on UK local content is more extensive. Scottish Renewables (2014) published an in-depth detail of the supply chain for the East Anglia 1 project with which aimed to deliver 50% UK local content –in line with the UK target of all offshore wind achieving 50% local content by 2020. According to Renewables UK (2017b) offshore wind farms are well on the way to meeting this target as by 2017 the average local content was 48%. One of the major factors contributing to such a high UK content was the opening of the £310 million turbine manufacturing plant in Hull. The creation of this plant not only enables for UK local content in wind power project to be increased but also for expertise to be exported and for potential growth in inward investment (Lecca et al, 2017).

BVG (2013) published an offshore supply chain report, in which it was highlighted that balance of plant (export cables etc) was an area of concern as there was a low level of UK expertise with regards to the balance of plant for offshore wind. It has however been emphasized that there is a level of synergy between the process used in the balance of plant for offshore wind and that in the Oil and Gas sector (BVG, 2014). With the recent downturn of the UK oil and gas sector there may be the possibility for companies to diversify and to adapt processes from the Oil and Gas sector to grow the UK balance of plant supply chain thus increasing UK content further than the 50% goal by 2020.

For Scotland, with there currently only being one full operational fixed offshore wind farm[69], the level of detail on local content is much less than for the UK as a whole. BVG (2012) reported on the CAPEX supply chain for the Robin Rigg wind farm and found that 11% of the total value was contracted to Scottish companies, with 37% to UK based companies. The report separates the total CAPEX into 3 stages (project management, balance of plant and install & commissioning). While it was reported that 100% of the project management was from UK companies only 5% was attributed to Scottish companies. The report identified that none of the balance of planet contracts were assigned to Scottish companies with the rest of the Scottish content derived from the 21% local content from install & commissioning. From the impact reports of both Beatrice (Beatrice Offshore Windfarm Ltd, 2017) and Neart Na Geoithe (FAI, 2017) we find that the local content for CAPEX are expected to be 22% and 25.2% retrospectively.

In the public domain there is information regarding much of the large tier 1 supply chain for the Beatrice projects (4coffshore, 2017[70]), from which we find that two large contracts were given to Scottish companies – one for the manufacturing of substations and the other manufacturing of offshore transformer modules (OTMs). Burntisland Fabrications Ltd – based in Fife – won the contract (valued at £100 million) to manufacture 26 of the 84 foundation platforms. It has been estimated that this one contract has supported 200 jobs over a two year period with the first 10 of these structures having been supplied in August 2017 and the remaining 16 being ready for April 2018.

Even with this large Beatrice foundation contract, in late 2017 Burntisland Fabrications Ltd faced increased financial problems with closure becoming a real possibility. Due to the involvement in several nationally important projects, including Beatrice, the Scottish

[69] Robin Rigg with Beatrice and Aberdeen Bay in development.
[70] http://www.4coffshore.com/windfarms/beatrice-united-kingdom-uk53.html

Government aided in brokering a deal to secure the long term future of the company. A takeover deal was reached in April 2018 with Canadian construction company JV driver, but there were still considerable job losses. These issues faced by Burntisland Fabrications Ltd highlight the potential problems for setting stringent local content targets for offshore wind farms – especially in smaller economies such as Scotland. There needs to be an existing capacity of experience (companies) in the region to meet these local content targets, otherwise there is the potential of delays/financial difficulty in projects.

The other large Scottish Beatrice tier 1 contract, for two 300MW offshore transformer module (OTM), was awarded to Babock based in Rosyth. These OTMs are expected to be completed by mid-2018 while securing 60 skilled jobs during that period (Scottish Construction Now, 2017[71]). While there is information available on the large tier 1 contracts it is much more difficult to find information further down the supply chain (tier 2 etc). It is advantageous for detail on these lower tier contracts to be known to determine local content share at each stage of development.

4.4 The IO methodology

In Section 3.2 the development of IO tables was explained in detail, this section gives details on how these tables are used for economic modelling. The focus of this section is a single region demand driven IO model[72] based on the 2012 Scottish IxI tables with disaggregated electricity sector, developed in Chapter 3. Much of the information and mathematical analysis of IO modelling in this section follows Miller and Blair (2009). These models are known as demand driven, as explained in Section 4.3.2 the supply side is passive, thus the economic impacts are driven by the changes in demand.

4.4.1 Mathematical representation

[71] http://www.scottishconstructionnow.com/14579/babcock-secures-fabrication-contract-for-moray-offshore-project/

[72] This single region model can also be extended to a multi-region model and

Fundamentally IO models are based on a set of simulations equations which records the sectoral linkages of an economy, which produce the crucial Leontief inverse matrix. To begin, for a sector (i) of the economy the output is given by the equations below.

$$x_i = z_{i1} + \cdots z_{ij} + f_i \qquad (4.1)$$

$$x_i = \sum_{j=1}^{n} z_{ij} + f_i \qquad (4.2)$$

Sectoral output, x_i, is a combination of z_{ij} (the total of industrial sales from sector i to j) and the final demand for sector (f_i). The component z_{ij} is the intermediate sales which are used in the development of other products, whereas f_i is the final consumption of sector i. In terms of the IO tables the intermediate sales are related to the top left quadrant of the IO table (Chapter 3) with f_i the information contained within the top right quadrant of the IO table.

Extending Equation 4.2 to each sector of the economy we have a straightforward framework whereby the output of sectors will either be used as an input to other sectors or consumed in the final form.

Expanding Equation 4.2 for the full economy gives a matrix for sectors i to n.

$$\begin{bmatrix} x_i = z_{i1} + \cdots z_{in} + f_i \\ \ldots + \cdots . + . \\ \ldots + \cdots . + . \\ \ldots + \cdots . + . \\ x_n = z_{n1} + \cdots z_{nj} + f_n \end{bmatrix} \qquad (4.3)$$

This can be re-established in matrix form as:

$$\boldsymbol{x} = \boldsymbol{Zi} + \boldsymbol{f} \qquad (4.4)$$

As in Miller and Blair (2009) bold lower-case letters in Equation 4.4 represent columns vectors with upper-case bold letters used for matrices. **Z** is an n x n matric, **i** a vectors of 1s and both **x** and **f** a vector of n x 1.

Introducing the A matrix where $a_{ij} = \frac{z_{ij}}{x_i}$ allows for Equation 4.4 to be converted to:

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{f} \qquad (4.5)$$

The **A** matrix calculates the technical coefficients i.e the proportion of inputs that sector i contributes to the total outputs. Each cell within the **A** matrix gives the proportion of each input required to produce the sectoral output. When using this **A** matrix the assumption is made that the output is always generated by the same proportion of inputs (i.e Leontief production function).

From rearranging Equation 4.5 using **A**, we can arrive at the equation for sectoral outputs used for IO modelling:

$$\boldsymbol{f} = \boldsymbol{x} - \boldsymbol{A}\boldsymbol{x} \qquad (4.6)$$

$$\boldsymbol{f} = \boldsymbol{x}(\boldsymbol{I} - \boldsymbol{A}) \quad (4.7)$$

$$\boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}\boldsymbol{f} \quad (4.8)$$

$$\Delta\boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}\Delta\boldsymbol{f} \quad (4.9)$$

I is a Identity matrix where all the diagonals are ones and the rest of the matrix are zeros. $(\boldsymbol{I} - \boldsymbol{A})^{-\mathbf{1}}$ is the Leontief inverse matrix and used within the IO modelling to analyse the effect that changes in final demand will have on output. Each element α_{ij} within the Leontief matrix represents the direct and indirect output of sector i associated a unit final demand change of j.

Equation 4.9 illustrates that any change in the final demand of the economy will results in a change in the output of the sectors. From Equation 4.9 we find that with a change in demand the change in output is determined by the A matrix.

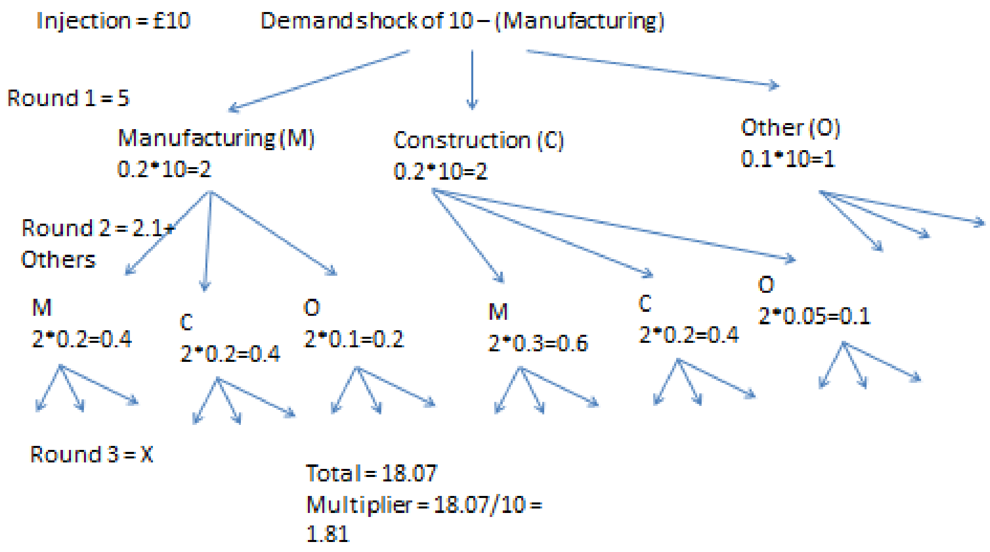
The demand driven IO can be used to measure the effect of an increase in demand will have on different economic variable - mainly output, employment and GVA – through the use of multipliers. There are two type of output multipliers (detailed below) which are sectoral calculated by totalling the j column elements within the Leontief inverse matrix.

Multipliers give the quantity of a given item (e.g employment) supported – directly or in-directly – by a unit of final demand for the output of each sector in the economy. An illustrative example is an output multiplier of 1.5 means that for every £1 change in final demand for the output of a sector the total output will increase by £1.50. In the analysis, with the final demand being treated as exogenous to the model, these multipliers are determined by the intermediate quadrant of IO tables.

There are two fundamental variations of the demand driven IO model (Type 1 and Type 2), which differ in their treatment of households within the model. For Type 1 the household sector is treated as exogenous to the model and not included in the **A** matrix. A Type 1 multiplier captures the direct and indirect change resulting from a unit change in final demand for the output of a sector. Direct effects are the simplest – if there is an increase in demand for a sector then the output of that sector will increase by at least that amount.

However, as is seen from the IO tables, each sector in the economy is linked to the others, thus an increase in output in one sector (which is reliant on inputs from others sectors) will also require an increase in the output of the linked input sectors, known as the indirect effects. This process of a sector being stimulated thus affecting others is a repeating process with the overall effect being built over several 'rounds' as illustrated in Figure 4.1. At each round there is a portion of demand for inputs which is not stimulating final demand, e.g through spending outside the regional economy (i.e imports) or a non-intermediate inputs, for example taxes and compensation of employees.

Figure 4.2: illustration of rounds of IO effects.



Source: Adapted from Armstrong and Taylor (1993)

Figure 4.2 illustrates the multiplier process. For an initial demand shock of 10 introduced in the manufacturing sector which has the following technical coefficients from the A matrix, construction (0.2), other (0.1) and manufacturing (0.2). In round one, to meet the increase in demand from manufacturing, each of the three input sectors must increase their output. Similar to round one, each of these three sectors in turn rely on output from their input sectors to meet their demand, seen in round 2. This is an iterative process with the magnitude of the supply chain effects gradually decreasing at each round. The overall effect, by the sum of all the rounds divided by the initial demand shock, is the indirect effect.

Type 2 demand driven models will also measure the direct and indirect effects along with a third effect, the 'induced effect'. An increase in the final demand will require some degree of increased labour input, reflected in the increased payment to compensation of employees. This in turn will generate additional increases – due the work force having an increased level of disposable income to spend - in final demand and thus output. This is known as the induced effect and is calculated by 'closing' the IO modelling to endogenise household consumption, by expanding the A matrix to add a row and column representing household labour input and consumption (Miller and Blair, 2009) .

These Type 2 multipliers can be calculated through a variety of methods, with pros and cons of each (Emonts-Holley et al, 2015). The difference in methods arises from the way in which household consumption is handled[73]. Emonts-Holley et al, 2015 indicate that while Miller and Blair (2009) Type 2 can overestimate the impacts, Batey underestimate impacts. The author indicates that it is advantageous to compare Type 2 results with other modelling techniques, as we do in Chapter 5 with CGE modelling. For the IO modelling used in this thesis the Miller and Blair methods is used for the calculation of Type 2 multipliers.

4.4.2 Limitations of IO modelling

There is no doubt that IO is a useful modelling tool for determining economic impacts, but like all modelling frameworks it does have limitations. IO is a special case of a CGE model with several assumptions, explained below. In Chapter 5 we build on the IO framework by simulating Scottish offshore wind using he AMOS CGE framework

The first limitation of the IO framework is the assumption of Leontief production functions whereby an output is always generated through the same share of sectoral inputs. Using a Leontief production function is not as problematic for electricity generation as it is for other sectors. As detailed in the previous chapter of this thesis to produce an output there are two main inputs to the electricity generation – fuel and O&M. Both these are fixed inputs relating to output thus a Leontief production is sensible for the electricity generation sector.

However in our modelling we are investing the impacts of increasing Scottish offshore capacity, which involves increasing the demand other sectors in the economy (such as

[73] The three main approaches are Miller and Blair (M+B), Batey 1 and Batey 2. M+B endogenise all household consumption and assumes that all household income is from wages thus consumption is normalised using this variable from the IO accounts. The Batey methods account for exogenous household expenditure with Batey 1 using external sources for normalisation while Batey 2 using total household consumption.

construction). In these sectors there is the possibility of substitution of inputs, particularly between labour and capital, and as such the use of a Leontief production function does limit the modelling. This limitation is overcome through CGE models by using other types of production functions (such as CES), which allow input and factor substitution in response to the change in relative prices.

Also in demand driven IO models the supply side is assumed to be completely passive with changes in economic activity attributed to the change in demand. This assumes that the increase in demand is always met without increasing pressure on the prices, wages or labour supply. For the electricity generation sectors, which are not labour intensive, this will not be a significant problem. But as mentioned above in our IO model we increase demand of several other sectors in the economy (with higher labour intensities than electricity generation) which in turn would tightening the labour supply thus increasing the wages within these sectors.

With the increase in demand in these sectors there will be economy wide increase in price. This increase in prices coupled with increase in wages can harm the competiveness of sectors, especially export intensive, known as crowing-out effects. The use of the AMOS CGE framework allows for variations in prices, wages and labour supply to be determined.

Another limitation of IO models are that they are 'static' with being based on information contained within one IO table. As identified in Chapter 3 these IO tables it only provides a snapshot of the economy and of course the economy changes dramatically over time, which needs to be kept in mind for long term simulations. This is of particular importance for the electricity sector with the Scottish electricity system currently under a major transformation in the move towards renewables.

One final limitation of the IO framework is that with impacts determined solely by the demand shocks and IO tables, legacy effects cannot be determined. With changes in prices, wages and labour supply once the demand expenditures stop there will still be changes to economic activity – which are known as legacy effects.

These limitations give the motivation for using CGE modelling to measure the effects of Scottish offshore wind. While the AMOS CGE used in Chapter 5 is still calibrated to 2012, it allows for variations in the prices, supply side constraints and substitution through the use of production functions other than Leontief.

4.5 Construction of IO demand shocks.

The previous sections provided an overview of the mechanics of IO as a modelling framework. This section gives detail on the development of the offshore wind demand shocks for IO modelling. The creation of these demand shocks was carried out in several stages. As seen in Section 4.3, these steps are typical of IO studies.

1. Estimation of potential MW to become operational by year
2. Breakdown (per MW) of offshore wind farms costs, per year
3. Local content for Scottish offshore wind farms
4. Allocation of costs to economic sectors in IO model

4.5.1 Estimation of potential MW to become operational by year

The importance of determining the potential MW per year of capacity ensures that the results will be realistic. Several different sources were used for the estimations of MW per year including project websites (SSE, 2017; Moray East, 2017)[74], EIA reports, news articles and external meetings. Like the modelling applications in the literature, there are several different simulation scenarios carried out, such as variations in capacity and degree of local content.

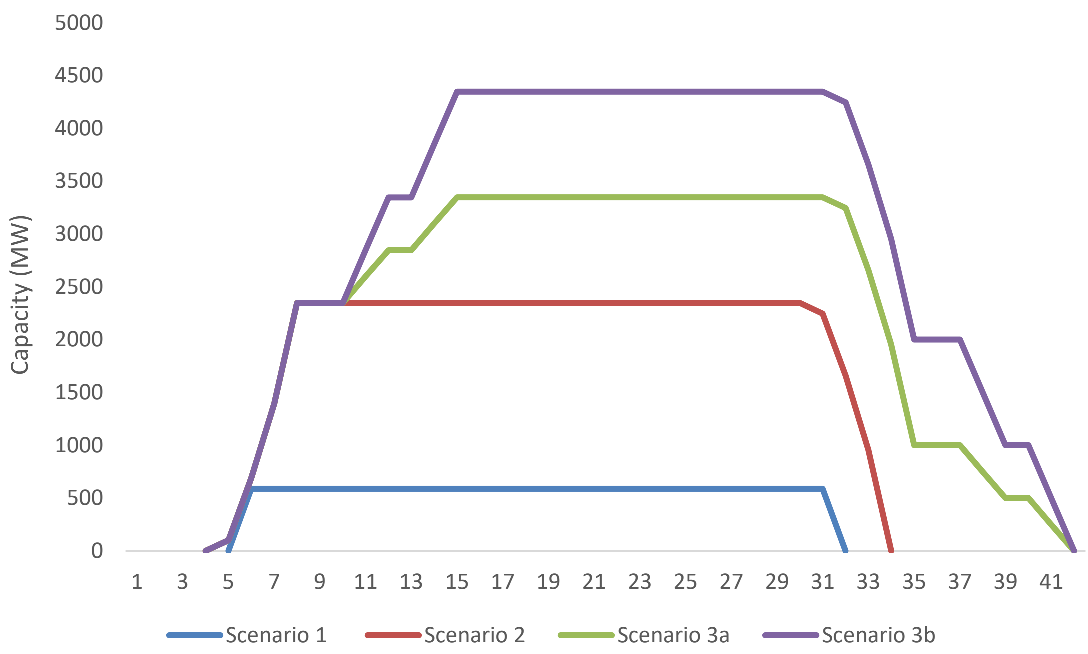
As detailed in Section 4.1, the focus of this thesis is the economic impacts of Scottish offshore wind as a whole – not project specific. As such we investigate the potential economic impacts of an increase in the local content. Along with the simulations in this scenario for a single wind farm with local content based real data; we also simulate the same wind farm but change

[74] http://sse.com/whatwedo/ourprojectsandassets/renewables/beatrice/; http://www.morayoffshore.com/

estimates on the local content to explore the effects of potential growth in the Scottish offshore wind supply chain.

Figure 4.3 Illustrates the cumulative capacity for each of the modelled scenarios, with explanation of each is given below.

Figure 4.3: Cumulative offshore wind capacity for the modelling scenarios.



Scenario 1 (One wind farm with low and high content assumptions) - l: One mid-sized 'generic' 588 MW wind farm to become fully operational during 2019. This Scenario allows for the effects (both magnitude and time-varying) of one wind farm to be easily identifiable. Also, as there has already been economic reports for single Scottish wind farms this scenario is used as a comparison between the reports and the works developed in this PhD. Within this scenario several different simulations are run with the first two being based on the Scottish low and high content data acquired, detailed in section 4.4.3.

Scenario 2 (Scottish planned capacity with low and high content assumptions): The objective of this PhD is to determine the overall economic impact of Scottish offshore developments thus in scenario 2 we model the full development of all planned capacity in Scotland which amounts to the 588 MW from Scenario 1 plus an extra 1.76 GW [75]of capacity by 2025[76]. This is the first time (to our knowledge) that the full economic impacts of all Scottish offshore planned capacity have been modelled. The local content for this scenario is based on the data on the low and high values from the data acquired for this thesis

Scenario 3 (Estimates growth scenarios with low and high content assumptions): After 2025 two simulations are run – gradual (3a) and accelerated (3b). These were chosen as the future growth for offshore wind can be difficult to determine, with such a slow development up to this point. This scenario builds on scenario 2 with gradual growth simulating an extra 1GW of capacity between 2025 and 2030, with accelerated an extra 2GW in the same period.

The purpose of this final scenario is to give extended outlook. It is noted that this scenario is not as robust as the previous two. In the previous two scenarios are based on planned developments which are most likely to go ahead. As identified in Chapter 1, to date Scottish offshore wind generation has been limited and can be difficult to predict. Also, the fundamental problem with IO model (explained in Section 4.2.2) is that it is based on a transactions from a single year (2012) based on IO tables making long term scenarios difficult to validate. In the long term the cost of offshore wind is likely to change dramatically, there will be local content differences and as matter of policy there may be another favoured technology (e.g floating)(FAI, 2017a).

For each of these scenarios the cost breakdown by year and stage of development must be determined. Overall there are three main stages of development.

[75] The value of planned construction was correct at the time of writing but this may change slightly with the projects still in development.
[76] This information is based on the Renewables UK (2017a) data and only the wind farms with clear timelines are included. The wind-farms included in this scenario are: Beatrice, Moray Firth east, Neart Na Gaoithe, Inch Cape and Aberdeen Bay.

Development expenditure – Costs costing in the planning and development of projects such as environmental surveys, planning of development and production of the Environmental Impacts Assessment (EIA) etc.

Capital expenditure – The largest expenditure in the development of offshore wind farms. Includes the turbines, foundation, electricity system as well as the expenditure on installing each of the components.

O&M expenditure – The maintenance costs occurred during the lifetime of the wind farms which for offshore wind is significant due to the operation environment.

With the different scenarios outlined the next stage was to breakdown the cost of offshore wind per MW, which is detailed in the next section.

4.5.2 Breakdown (per MW) of offshore wind farms costs

Combinations of both publically available and confidential sources were used for the calculation of the costs associated with offshore wind development in Scotland.

In implementing the demand shocks, development and capital expenditure are grouped together as the overall CAPEX covering the full development of wind farms from initial planning to full operation. For this CAPEX an estimate is needed of the total expenditure per installed MW, a figure in which there is much variation throughout the literature. Initially an estimate of £3 million per MW was used – in line with UK round 3 wind farms (DB climate change advisors, 2011) - but by investigating the Beatrice offshore windfarm Ltd (2017) data suggested an expected CAPEX of £4.2 million per installed MW of capacity with estimations for Neart Na Gaoithe being up to £4.45 million per MW (FAI, 2017). This large variation in cost is associated with the difference in operating environments. Mone (2017) also noted this with estimates for £/MW ranging from £2.6 million to £4.5 million. In the demand shock model a value of £4 million per MW was chosen for the Scottish offshore wind CAPEX[77] which not only accounts for the variation in operating environments but also as we are looking at future project, the natural reduction in costs as more farms are built.

With the estimation of CAPEX per MW now determined, this has to be separated into the expenditure for different stages of CAPEX to get the timing and sectoral composite of expenditures. Information from The Crown Estate (2010) and BVG (2010), along with some reports made available for this project were consulted to calculate estimates from the percentage breakdown of each stage. From these sources we provide the estimates in Table 4.2

Table 4.1: Cost breakdown of development and capital costs.

Stage of development	Percentage of Capex
Environmental Survey	0.27%
Sea bed survey	0.60%
Met Mast	0.34%
Development services	2.19%
Turbines	39.98%
Foundations	16.66%
Array cables	1.33%
Export cables	4.00%
Offshore substations	5.67%
Onshore electrical	2.27%
Install + Commission	26.65%
Total[78]	100%

Source: The Crown Estate (2010), BVG(2010) and reports made available for this PhD

[77] This was taken by investigating the named sources above as well as the project level information available for this project. Information in this project data was on associated costs and information on local content at a range of stages

[78] May not sum due rounding.

Before investigating this table further it must first be pointed out that these sources are for a 'generic' wind farm. Each offshore wind farm will be unique and the cost breakdown is dependant of a variety of different factors including (but not limited to) location, layout, type of turbine (Burton et a, 2011, Chp 5). As we are focusing on Scotland as a whole, instead of focusing on a specific wind farm, the information found in these papers is appropriate to use as we are not focusing on one type of wind farm. Also these breakdowns – as with the modelling as a whole- are focused on fixed foundations turbines. There is a growing potential for floating offshore wind in Scotland, however as these are relatively new technologies, it is difficult to predict their future deployment and accompanying costs (Carbon Trust, 2015)[79].

Table 4.2 shows the dominance of the cost of the turbine, which represents nearly 40% of total CAPEX. This is to be expected, but in terms of the economic benefits to Scotland of future developments this is unhelpful as nearly all turbine components are developed outwith Scotland thus reducing the economic benefits to Scotland. From Table 4.2 it is found that the development stage represents <4% of overall CAPEX but these are the stages – planning, surveys etc – at which a project is likely to fall through. The two other stages with the highest cost are foundations and installation & commissioning, both of which have the possibility of using Scottish content through the use of Scottish ports as well as local labour.

4.5.2.1 Timing

All of the costs of an offshore wind farm do not occur at the same time during the development. This is accounted for in the demand shocks. By investigating the EIA reports of the Scottish offshore wind farms[80] currently in-development along with the data available for this project, the cost per annum break-down was calculated for a 'generic' Scottish offshore wind farm found in Table 4.3 below.

[79] A demonstrator floating offshore wind project in Scotland "Hywind" became operational in October 2017.
[80] Arcus Renewable Energy Consulting ltd (2012), Repol and EDP renewables (2014), Mainstream Renewable Power (2012), Seagreen Wind Energy (2012) , Moray Offshore Renewabls Ltd (2013)

Table 4.2: Yearly breakdown of CAPEX costs.

Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
0.37%	1.82%	16.43%	32.12%	27.13%	22.11%

Source: Author's calculation

From Table 4.3 we find that expenditure from offshore wind is concentrated on the latter half of development. Years 1 - 2 of the project are labour intensive (planning etc) where the expenditure is relatively low. However, once the construction of the wind farm beginnings (year 3) the project becomes capital intensive thus increasing the cost dramatically.

Having established the volume and time path of CAPEX for impact evaluation the next stage of the model was to develop costing for the O&M for offshore wind in Scotland. In Chapter 3 when disaggregating the electricity sector, estimates of the O&M figures for Robin Rigg wind farm were used. However, for this analysis we do not use these data because this project was a rather shallow near shore wind farm when compared with future of Scottish offshore wind farm[81] – something which would reduce the O&M (GL Garrad Hassan, 2013).

For onshore power generation technologies the O&M strategy is based on scheduled and reactive maintenance whereby if a problem occurs it will be repaired within reasonable time, while if no problems occur scheduled maintenance is carried out at a predefined time. This is possible on-shore as there are low access problems, however the same cannot be said for offshore wind – or any offshore technology. If a component within an offshore wind turbine/farm stops functioning then there are several factors which determine when the maintenance can be carried out including ship availability and weather. If no ship is available or weather is poor – which is a particular problem for the North Sea – then turbines (or even full farms) will need to reduce or stop generating entirely, reducing cost effectiveness. It is for these reasons O&M for offshore wind farms is seen as an key area for R&D investment, with

[81] Robin Rigg is 11km from shore wind waterdepths < 13m, whereas the planned offshore wind farms are further (in excess of 20km) with water depths up to 50m.

research being carried out on different maintenance strategies (for example Dalgic et al (2015)).

The cost of O&M varies greatly by source thus for the IO model a best estimate had to be made using the available information. Data from Carrol et al (2017) on O&M cost by turbine type and distance to shore was used to calculate a 'best' estimate average O&M for generic Scottish offshore wind at £66,229 per MW per year – which is much higher than the Robin Rigg data of £46,301 per MW (BVG, 2012).

Another part of O&M which needs to be taken into account is the lifetime of the turbines, for the purpose of the IO model it was assumed that the operational lifetime (not accounting for extension or repowering) of a windfarm would be 25 years. In the model the decommissioning of offshore wind is not taken into account as there are several unknown variables which will affect this process. With the CAPEX and OPEX known, we now have the demand shocks in the form overall expenditure by year by development stage of the wind farm. The next stage of the model is to include 'local content'.

4.5.3 Local content from Scottish offshore wind farms

In Section 4.2 the concept of local content was detailed with information given on local content for Scottish/UK wind farms, as well as, the method used for calculation. For our modelling the local content estimations are needed for a generic (i.e no specific) offshore wind farm at each stage of development. These estimations were calculated using publically available information on wind farms (including the Beatrice information explained in Section 4.2.2) along with confidential Scottish content data[82]. Using these sources it was estimated that overall the Scottish content for a 'generic' Scottish offshore wind farm ranged from between 14.01% and 17.06% of total CAPEX value.

[82] The data available for this project was a survey carried out of Scottish offshore wind farm developers in 2015. While we did not have access to project level data, there was information available on the Scottish averages on the expected local content share at different stages of development.

4.5.4 The bridge matrix and IO tables

With the local content information included the model now has Scottish expenditures by year by stage of development. However for IO modelling the demand shocks must be assigned to sectors within the IO tables, which these stages of development are not. To overcome this a conversion was carried out using a offshore wind bridge matrix linking categories expenditures to industrial sectors.

This bridge matrix converts the spending at offshore wind stages to SIC codes found within IO tables and was originally developed by BVG. In the matrix each of the stages is related to various SIC codes based on percentage of spending. The bridge matrix has been used in several project to determine the economic impacts of offshore wind in the UK including (ORE Catapult, 2014) and (Lecca et al, 2017). As found from Table 4.4 this bridge matrix uses and aggregated SIC codes thus the need to aggregate the Scottish IO to match with the different stages of offshore wind developments.

Table 4.3: Offshore wind bridge matrix.

Bridge Matrix	**Glass and ceramics**	**Clay**	**Iron and steel**	**Generation gas**	**Generation offshore wind**	**Construction**	**Other Manufacturing and trade**	**Air transport**	**Other transport**	**Services**
Environmental Survey	0%	0%	0%	2%	0%	5%	0%	0%	10%	83%
Seabed survey	0%	0%	0%	2%	0%	5%	0%	0%	10%	83%
Met mast	0%	0%	0%	2%	0%	5%	0%	0%	10%	83%
Development survey	0%	0%	0%	2%	0%	5%	0%	0%	10%	83%
Blades	73%	0%	0%	2%	0%	10%	5%	0%	5%	5%
Hub assembly	0%	0%	73%	2%	0%	10%	5%	0%	5%	5%
Gearbox	0%	0%	73%	2%	0%	10%	5%	0%	5%	5%
Electrical system	0%	0%	73%	2%	0%	10%	5%	0%	5%	5%
Other	0%	0%	73%	2%	0%	10%	5%	0%	5%	5%
Tower	0%	0%	78%	2%	0%	10%	5%	0%	5%	0%
Foundations	0%	20%	58%	2%	0%	10%	0%	0%	5%	5%
Array cables	2%	0%	35%	2%	0%	10%	41%	2%	5%	3%
Export cables	2%	0%	40%	2%	0%	10%	38%	0%	5%	3%
Offshore Substation	0%	0%	80%	2%	0%	10%	3%	0%	0%	5%
Onshore electrical	0%	0%	20%	5%	0%	30%	0%	0%	40%	5%
IC foundations	0%	0%	20%	20%	0%	0%	5%	0%	50%	5%
IC cables	0%	0%	20%	20%	0%	0%	5%	0%	50%	5%
IC turbines	0%	0%	20%	20%	0%	0%	5%	0%	50%	5%
IC offshore Substation	0%	0%	20%	20%	0%	0%	5%	0%	50%	5%
O&M	0%	0%	0%	0%	60%	10	0%	4%	0%	26%

Source: BVG(2014)

From Table 4.4 we find that the stages of development can be separated into the several industrial sectors based on a percentage breakdown. A noteworthy point from Table 4.4 is that the electricity sector has been disaggregated with there being a separate offshore wind sector – unlike in the original IO tables with a single electricity sector. With this information, we are able to take full advantage of the disaggregated 2012 Scottish IO developed in chapter 5. It would be ideal to use the full 98 sector Scottish IO table however from the bridge matrix it is evident that several sectors have been aggregated and as such, for modelling purposes, the IO table from Chapter 3 must be aggregated to match. Carrying out this aggregation creates an 23 sector IO table with 8 electricity sectors (7 generation), the list of aggregated sectors is giving in Appendix 4A.

With the local expenditures now converted into industrial sectors the full demand shocks are ready to be applied to the IO model. The next section (4.5) presents the results for this analysis.

4.6 Results for IO demand shock

In Section 4.4 it was identified that there were several different scenarios run for potential growth of offshore wind development in Scotland. This section will examine the results from each of the scenarios. In it important to note that these results are in present (2017) values with a discount rate in line with HMT of 3.5% used (HMT, 2018).

4.6.1 Scenario 1 – Single 588 MW wind farm

This scenario was to estimate the economic impact of a single medium to large capacity offshore wind farm with results presented in Tables 4.5 and 4.6 below.

Table 4.4: Single medium-large capacity wind farm with low content assumption (NPV)

Low content assumption					
CAPEX					
	Demand Shock	*Type 1*	*Type 2*	*Type 1 multiplier*	*Type 2 multiplier*
Output (£m)	*314.2*	444.0	830.5	1.4	2.6[83]
GVA (£m)	*132.3*	189.6	293.0	1.4	2.2
FTE (Person years)	*1,866*	2,893	5,031	1.5	2.7
OPEX					
	Demand Shock	*Type 1*	*Type 2*	*Type 1 multiplier*	*Type 2 multiplier*
Output (£m)	162.2	207.4	427.2	1.3	2.6
GVA (£m)	112.5	133.5	192.3	1.2	1.7
FTE (Person years)	1,975	2,328	3,544	1.2	1.8
Total					
	Demand Shock	*Type 1*	*Type 2*	*Type 1 multiplier*	*Type 2 multiplier*
Output (£m)	*476.4*	651.3	1,257.7	1.4	2.6
GVA (£m)	*244.8*	323.1	485.3	1.3	2.0
FTE (Person years)	*3,841*	5,221	8,575	1.4	2.2

[83] The difference between the Type 1 and Type 2 is Including the induced impacts. There is a large difference in this modelling indicating the sectors impacted are labour intensive.

Source: Author's calculation

Table 4.5: Single medium-large capacity wind farm with high content assumption (NPV).

High content assumption					
CAPEX					
	Demand Shock	*Type 1*	*Type 2*	*Type 1 multiplier*	*Type 2 multiplier*
Output (£m)	368.1	518.6	975.6	1.4	2.7
GVA (£m)	156.3	222.9	345.1	1.4	2.2
FTE (Person years)	2,210	3,404	5,932	1.5	2.7
OPEX					
	Demand Shock	*Type 1*	*Type 2*	*Type 1 multiplier*	*Type 2 multiplier*
Output (£m)	205.5	262.7	541.1	1.3	2.6
GVA (£m)	142.4	169.1	243.6	1.2	1.7
FTE (Person years)	2,501	2,949	4,490	1.2	1.8
Total					
	Demand Shock	*Type 1*	*Type 2*	*Type 1 multiplier*	*Type 2 multiplier*
Output (£m)	*573.6*	781.3	1,516.7	1.4	2.6
GVA (£m)	*298.8*	392.0	588.7	1.3	2.0
FTE (Person years)	*4,712*	6,353	10,422	1.3	2.2

Source: Author's calculation

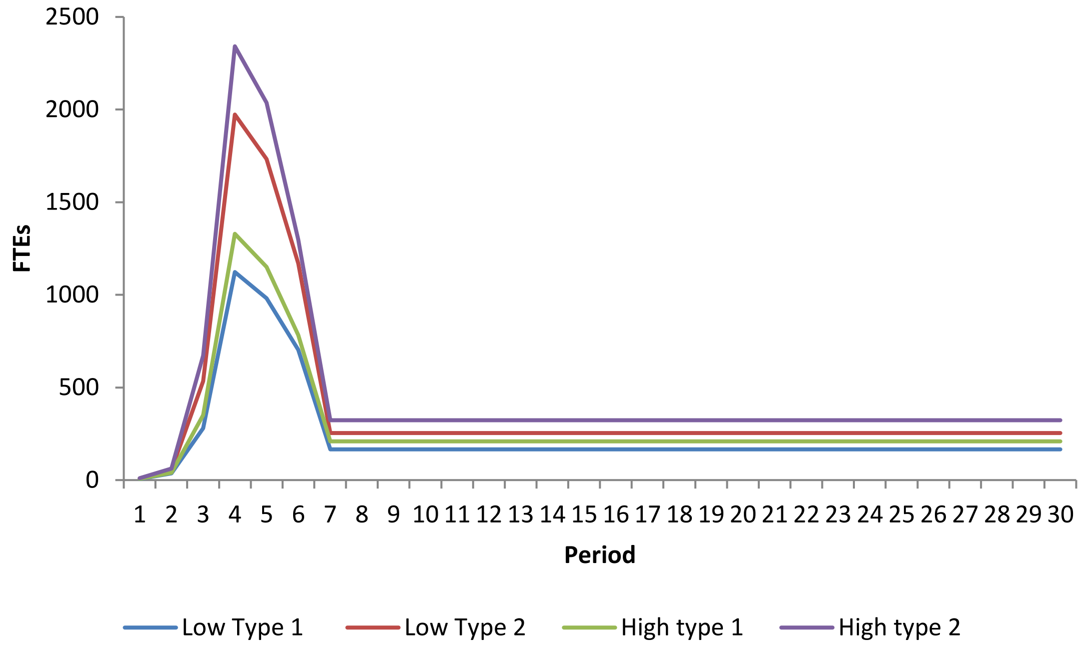
The simulations are carried out with both low (14%) (Table 4.5) and high (17.2%) (Table 4.6) content assumption for CAPEX and OPEX with the higher content having greater Scottish impacts (as would be expected). From Table 4.5 it is found that for a low Scottish content offshore wind farm – taking into account induced effects – will add £485 million of GVA with 8,575 PV of person years of employment. Looking at this in more detail it is found that 60.38% of the GVA attributed to the development and construction (CAPEX) of the wind farm while the remaining 39.62% is from the operation and maintenance stage. In the high content assumption this GVA increases to £580million (58.5% in CAPEX) with an extra 1783 FTEs.

When comparing the result from this simulation to the economic impact of other similar sized Scottish project we find interesting results. In the high content assumption it is found that during the construction stage of the project we calculated an increase in FTE of 5,933 jobs years which compares favourably with the information in the Beatrice economic report of around 5,800 job years. However comparing the GVA it is found that the Beatrice Offshore Windfarm Limited project (2017) reports a much higher increase of £513 million when compared with our £345.1million. These differences occur for several reasons: with a higher level of data available on the project, Beatrice Offshore Windfarm Limited project (2017) can model the local content for a specific wind farm whereas our model is based on a 'generic' Scottish wind farm. Upon when investigating the methodology they use, we find that a different method to attribute expenditures to SIC codes, another reason the results may differ.

In the FAI (2017) report for another Scottish offshore wind farm (140MW smaller than simulation 1) that there would be a predicted total increase of GVA of £827 million and 13,900 job years in employment. These are larger than the results for our (high content) simulation. As with the Beatrice report the model parameters are different than in the FAI (2017) compared with the IO used in this PhD – with the main difference attributed to the increase in local content and different IO table (2014) being used.

It is obvious that the economic will be vary greatly depending on the stage of development with Figure 4. 4 demonstrating this by giving the yearly employment.

Figure 4.4: FTE time distribution for a single wind farm.



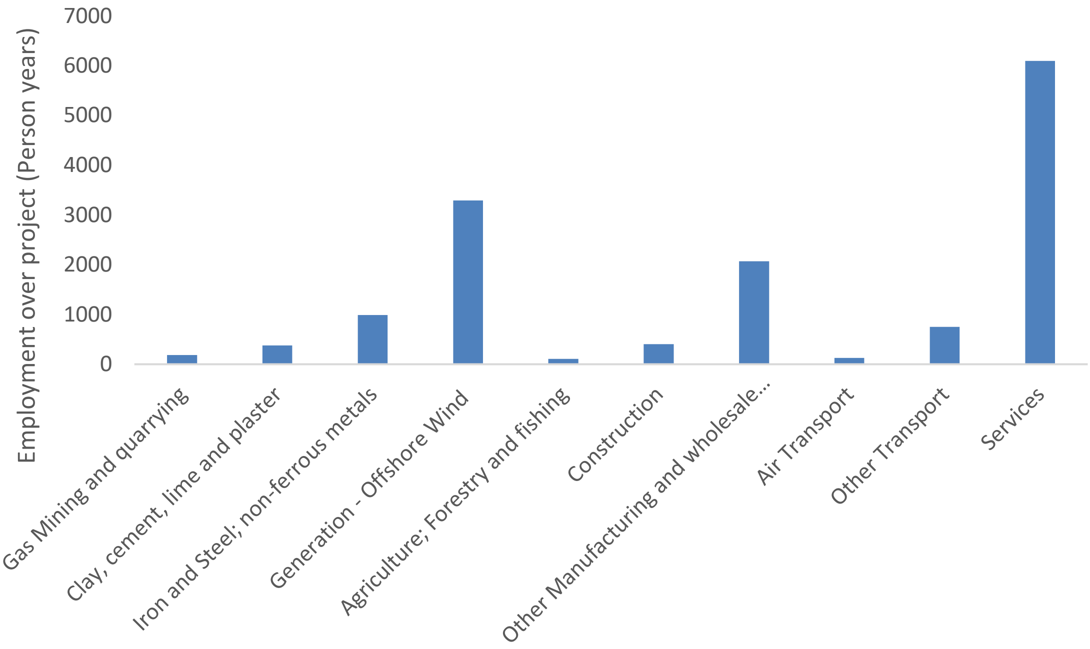
Source: Author's calculation

This figure shows that the CAPEX stage of development is much more labour intensive than the O&M stage. With the CAPEX employment following a similar pattern to the expenditure found in Table 4.2, while for O&M employment there is no variation year on year, which would be expected as there is no change in the cost or local content, i.e same amount of turbines and O&M base.

As well as employment varying over time, there will be sectoral variation in the number of players. Figure 4.5 gives the total employment by sector for the top 10 employment sectors for the high content Type 2 simulation.

Figure 4.5: Employment impact of one medium sized wind

farm on 10 sectors.



Source: Author’s calculation

The two sectors with the largest increase in employment are Generation- Offshore wind and Services. By investigating the above bridge matrix this is expected as all O&M costs are attributed to only these two sectors. Other sectors which are found to have noticeable increases in employment are Iron and steel; Construction and Other manufacturing – again expected due to the type of project being modelled.

With the single wind farm modelled the next stage of the thesis the cumulative impacts of all Scottish offshore planned capacity.

4.6.2 Scenario 2 – Planned capacity

Another scenario which was investigated was expanding scenario 1 with the development of an extra 1.76GW of capacity by 2025 – representing 4 medium size wind farms. The first

100MW to be operational by 2018, one 450MW by 2022, a second 400MW farm by 2023 and the final 300MW of capacity by 2023. Overall this represents and investment of nearly £7 billion in new offshore renewable energy capacity. Taking the same approach used in Table 4.5 but considering this larger investment we investigate the impact on the Scottish economy with headline results found below.

Table 4.6 Results Scenario 2 planned capacity NPV (Low content).

	Direct	Type 1	Type 2
Output	1,697.3	2,311.3	4,483.8
GVA (£m)	886.8	1,162.5	1,743.5
FTE	13,995	18,843	30,861

Source: Author's calculation

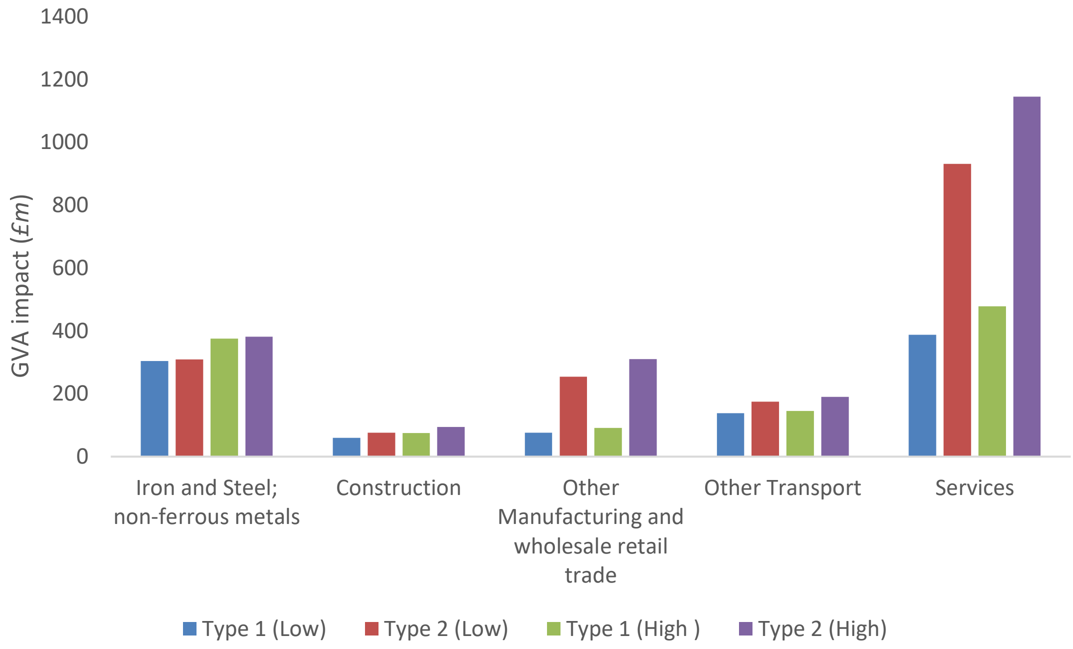
Table 4.7 Results Scenario 2 planned capacity NPV (high content).

	Direct	Type 1	Type 2
Output	2,055.8	2,789.9	5,439.3
GVA (£m)	1,087.7	1,418.0	2,126.6
FTE	17,244	23,052	37,708

Source: Author's calculation

As is to be expected the increase in economic benefits is dramatically increased with an increase in capacity by 2025. The larger capacity leads to a total GVA increase (based on type 2 multipliers) of between £1,743.5 million (low content) million and £2,126.6 million (high content) equivalent to 0.65% and 0.79% of Scottish GVA in 2012 retrospectively (for output the increases from 0.85% and 1.03%). Obviously this GVA is not evenly distributed throughout the economy; some sectors will see a greater increase in activity than others. This is demonstrated below with the 5 largest detailed in Figure 4.6.

Figure 4.6: GVA by economic sector.



As with employment the GVA impacts vary greatly depending on the sectors, content and multiplier type. For most of the sectors – apart from Iron and Steel – the Type 2 low content GVA impacts are greater than Type 1 high content. This indicates that these sectors a labour intensive with much of the economic impact driven by the increase in household income. For Iron and Steel the opposite is true with the Type 1 high content greater than Type 2 low content, meaning that the majority of economic impacts arise from the direct demand.

4.6.3 Scenario 3 – Planned capacity with gradual and accelerated growth after 2025

As identified earlier, the growth of offshore wind in Scotland has been slow and, even though there is a large potential, the future growth is uncertain. Because of this in scenario 3 there were two different simulations run – one for a gradual growth scenario and another for an accelerated growth scenarios. Both scenarios increase capacity by 1.76GW by 2025 then in the gradual simulation an extra 1GW is developed by 2030 while in the accelerated growth scenario by 2030 the capacity is increased by a further 2GW. Table 4.10 gives the headline figures for these simulations in present value.

Table 4.8: Results for gradual and accelerated growth scenario (NPV).

Low content						
	Gradual growth			Accelerated Growth		
	Direct	Type 1	Type 2	*Direct*	Type 1	Type 2
Output	2,300.0	3,131.3	6,074.3	2,902.7	3,951.3	7,664.8
GVA (£m)	1,205.8	1,579.3	2,366.4	1,524.8	1,996.1	2,989.2
FTE	19,082	25,649	41,930	24,169	32,455	52,999
High content						
Output	2,783.6	3,776.6	7,362.0	3,511.4	4,763.4	9,284.7
GVA (£m)	1,477.1	1,924.0	2,882.8	1,866.5	2,429.9	3,639.0
FTE	23,472	31,322	51,156	29,700	39,593	64,605

As would be expected there is greater economic benefit with a sustained growth in offshore wind in Scotland, with the potential for up to 64,600 FTEs this. For these economic benefits to be realised a large.

It is important to recognise the effects of a passive supply side in these simulations. 64,600 FTE represent a noticeable proportion of Scottish Employment in 2012 (2.15%) and the scale of these impacts from IO models may be unrealistic. As detailed in Section 4.2.2 the IO model is assumed to be passive with no changes in prices, wages or labour supply. However, with such large expenditures over an extended period of time there would be expected changes in these variables which would impact the overall economic impacts. In the next chapter we deal with these problems by using a CGE model.

4.7 Conclusion and contributions

This chapter has investigated the potential economic impact of current and proposed Scottish offshore wind generation projects through the use of an IO methodology. As identified in Chapter 1 the energy trilemma has evolved to the energy quadrilemma, with economic development now identified as a key pillar of energy policy. Thus is it is beneficial for policy makers to know the economic impacts of projects which are part of an energy policy. Policy makers can then use these economic assessments to determine which project to grant consent and also if they can subsidies those giving value for money due to the local benefit.

IO modelling is a framework that is used extensively in academia and industry for impact assessments and as such is ideal as a starting point to investigate the economic impacts of Scottish offshore wind. Our model is based on the 2012 Scottish IO table, with a disaggregated electricity sector using the 2012 Scottish ElSA. The purpose of disaggregating the electricity sector is to reduce aggregation bias within the model, implying a higher degree of accuracy in the results.

Overall there were three scenarios modelled in in this Chapter: single wind farm; planned capacity; and planned capacity with growth to 2030. In each scenario there a different simulation run with particular attention paid to local content. Local content is becoming an increasingly important issue for offshore wind farms in Scotland as these are being taken into account when planning permission is being granted (Crown Estate Scotland, 2018). For our modelling in each scenario there is a low content and high content simulation, based on real data.

The IO framework works by introducing a change in sectoral demand which will leads to changes in other sectors and overall economy wide impacts. For each of the scenarios we use project information along with the local content data from which we build a time path of Scottish expenditure by offshore wind stage. This time path of Scottish expenditure by offshore wind stage is then converted to economic sector expenditures through the use of the offshore wind bridging matrix. The sectoral expenditures are then introduced into the model.

As would be expected there is large variations in the results. A single wind farm could create between 8,575 and 10,420 FTEs (person years) and add £588.7 million of GVA while all planned capacity has the potential of 37,710 FTEs and £2.13 billion of GVA. Finally in the growth scenario there could be job creation 2.15% of base year employment.

The contribution of this chapter is to investigate the potential economic impacts of future Scottish offshore wind as a whole. In the previous literature (FAI, 2017; Beatrice offshore wind, 2017) the focus has been solely on one wind farm. Also another contribution of this chapter is we investigate the impacts of variations in local content, which is becoming an increasingly important policy issue.

As identified in Section 4.3.2, even though it is widely used, there are several limitations of demand driven IO models – perhaps the most important being that there are no supply side constraints. In the real economy there will always be supply side constraints and as such we extend the economic analysis of Scottish offshore wind through the use of CGE modelling in the next chapter.

Chapter 5 – CGE Modelling of increased offshore wind capacity

5.1 Introduction

In the previous chapter Input-Output (IO) modelling was used to explore the potential economic impact of an increase in Scottish offshore wind capacity. While the IO methodology has been widely used in academia and industry to explore the impact of new renewable energy projects, as identified in Section 4.3, there are several limitations of IO modelling. Two of the fundamental limitations of IO modelling are: the assumption of a passive supply-side and the assumptions of fixed prices (Allan et al, 2007). Computable General Equilibrium (CGE) models can relax these assumptions, providing scope to identify the way in which IO assumptions impact upon model results as IO models have been known to overestimate impacts (Allan et al, 2014a). This chapter will investigate the economic impacts for Scotland in an increase in offshore wind capacity using a CGE model.

As identified in Chapter 4 an IO model is a special case of a CGE model with limitations on the supply-side and prices. The key principle behind CGE is that each sector within the economy is inherently linked to every other sector of the economy and a change in one will have an effect on others – either directly or indirectly. These linkages are recorded through the use of IO tables which are extended further into a Social Account Matrix (SAM) database – the key input with full CGE modelling systems.

With CGE, by basing the modelling on economic theory (such as profit maximisation) and real economy data (the SAM), many of the assumptions found within the IO framework are relaxed. Through the use of production functions other than Leontief, CGE allows for substitution, determined by relative prices, between factors – in particular labour and capital. Also CGE models allow for price variations and the effect they have on the economy.

One of the particular strengths of CGE is the timing of economic impacts, which we pay close attention to in the results. From Figure 4.4 we found that the timing of economic impacts are driven by the demand shock at that time period, thus at the O&M stage of the projects the (undiscounted) impacts are the same at each period. However, with CGE modelling this is not the case as the variation in prices etc will impact the impacts. Also in Figure 4.4 we find that with the IO method once the project finishes (i.e no demand shocks) there is no economic impacts after that period. However, there are likely still to be some economic impacts arising in later periods due to the changes in the baseline economy (labour supply, prices etc) from the project expenditures –known as legacy effects – and CGE accounts for these.

In this chapter we use a version of the Macro-Micro Model of Scotland (AMOS) family of CGE models (Harrigan, 1991) to evaluate the scenarios developed in Chapter 4 to measure the impact of Scottish offshore wind developments. The contribution of this chapter is that this is the first attempt at modelling the potential economic impact arising from Scottish offshore wind using this type of model. With using both modelling frameworks we can compare the results with the IO modelling, in a similar manner to Allan et al (2014a).

This chapter proceeds with an introduction to generic CGE modelling in Section 5.2 then explanation of the AMOSEVNI model in section 5.3. The modelling strategy is then discussed in section 5.4 with results in Section 5.5. Section 5.6 concludes.

5.2 CGE modelling

The fundamental concept used for the development of CGE models is the Walrasian theory of general equilibrium (Walrus,1926). Walrus (1926) specific an equilibrium model, through a series of simulations equations when – at a certain price – supply and demand are equal in all markets. Arrow and Debreu (1954), and Debreu (1959) were key in the development in the theory of general equilibrium.

In Johansen (1960) a 'fixed output stochastic model' benchmarked on 1950 Norway national account data was developed. The key contribution of Johansen was the identification of the behaviour of individual agent (Dixon and Rimmer, 2010). Through this identification, Johansen (1960) is accredited as one first attempts to solve a multi-sectoral economy in linearized equilibrium, Independent of the work carried out from Johansen (1960), Scarf (1967) established an algorithm to solve the Arrow and Debreu general equilibrium theory for the first time. In the work, Scarf calculated equilibrium prices for the first time –thus converting the theoretical general equilibrium theory of Arrow and Debreu to the computational setting.

5.2.1 Model structure

With the uses of CGE models varying greatly (Babatunde et al, 2017) there is no 'one size fits' all for the modelling structure, with the structure being driven by the questions to be answered. However according to, Shoven and Whalley (1992), the fundamental principle of all CGE models is the same in that there is a set of equations with a range of variables characterizing the economy along with a real database on the inter-industrial flows of the economy. In the modelling setup, CGE models are generally based on neoclassical economic theory whereby by consumers maximize their utility subject to a budget constraints while producers maximize profit/minimise cost.

In Chapter 3 a description of IO tables, used to give detailed representation of inter-industrial flows within an economy for a year, was given – these IO accounts are used to capture the inter-industrial production and consumption of goods and services in an economy in any given year. An extension of the IO tables known as a Social Accounting Matrix (SAM) - incorporating transactions and transfers between institutions related to the distribution of income of the economy[84] (Miller and Blair, Chp 6) – is used as the base database within CGE models.

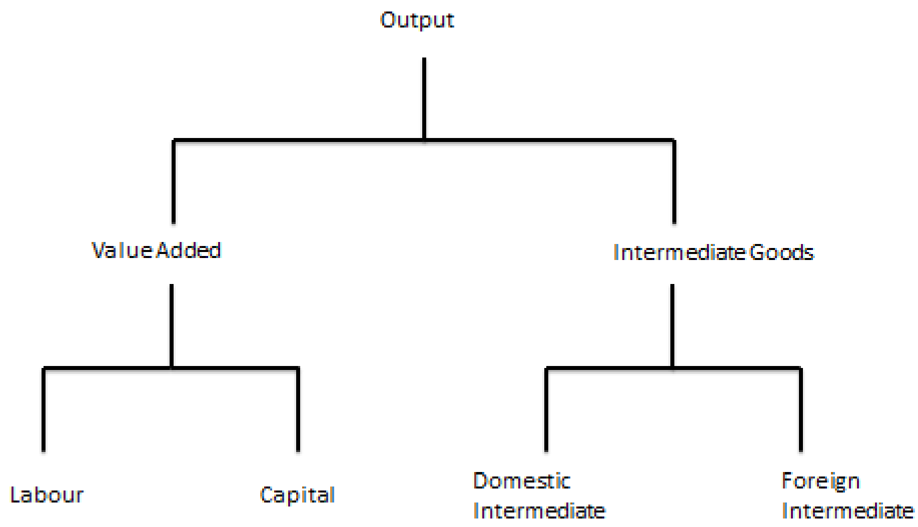
Along with the SAM database, the choice of utility and production functions is of the upmost importance within CGE modelling, depending on the purpose. The common production functions used within CGE models are: constant elasticity of substitution (CES), Cobb Douglas (CB) or Leontief fixed proportion. The model also will have a number of key

[84] For the development of a SAM, information found within and Income-Expenditure account is combined with the standard IO tables. This gives a more comprehensive picture of the nature of economic linkages in the economy (Ross,2017).

exogenous parameters specified such as the elasticity of substitution between domestic and external goods & services (Emonts-Holley, 2016) often based on the Armington function (Armington,1969) .

Within CGE models it is standard practice for nested product functions to be used to production technologies used by firms, with an example of a two level structure given in Figure 5.1

Figure 5.1: Two level production function.



Source: Gilmartin (2010)

From the circular flow of the economy the production of goods and services are dependent on both factor and intermediate inputs. Sectors combine intermediate goods and value added into a final product using some combination of labour and capital as represented by the production function. An example of this for automobile manufactures – taken from Burfisher (2011,Chp 5) – is that firms may find it simple to substitute employees for machines (factor inputs) whereas substitution of tyres and steering wheels (intermediate inputs) is impossible as the two have completely different production functions.

Read from bottom to top, the nested structure allows for the use of different inputs in production, the two level nested structure in Figure 5.1 has three nests. The combination of labour and capital gives the value added nest while both the domestic and imported intermediate goods combine to give the intermediate composite nest. Combining the two composite nests results in the total output of the industry. It should be noted that this structure allows for more nests to be added[85] if needed. Two advantages of the use of nested production functions are: a reduction in computational time and the possibility of using different elasticities of substitution[86] (McIntyre, 2012).

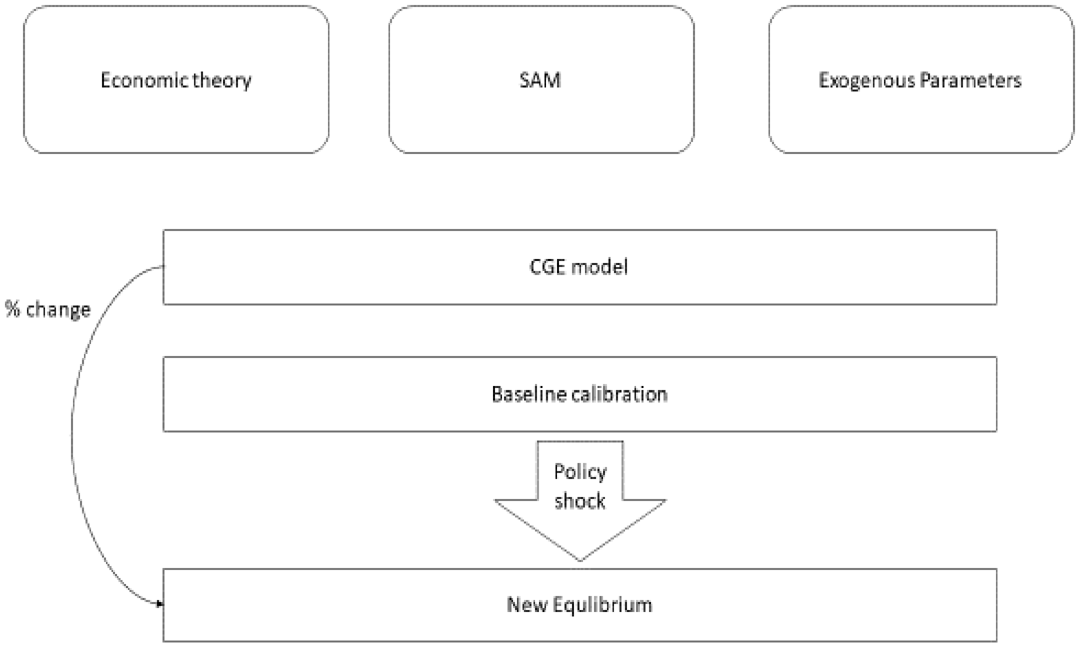
5.2.2 Simulation strategy

Figure 5.2 below shows the computational processes carried out modelling

[85] Ross (2017) separates labour by skill, for example.

[86] Elasticity of substitution is the ratio of the relative change in demand of two products with a relative change in prices. This is a key variable for CGE modelling as it determines the easy of substitution between products. An elasticity of substitution: <1 the products are complements: 1 perfect substitutes and >1 gross substitutes.

Figure 5.2: Computational process of CGE modelling.



Source: Emonts-Holley (2016)

Before any simulations are run a calibration is carried out by running the model without the introduction of any policy or exogenous demand shocks. This allows the model to reproduce the original data set (SAM) while setting up a reference equilibrium and key to the modelling, calibrate the parameters. From here the characteristics of the model are changes to implement policy changes or external demand shocks. Through simulation, a new equilibrium is determined from the use of the equations within the model. The shock in the model will cause price variations, affecting the consumption and productions and services until a new equilibrium point is reached.

Through these simulations the effect a shock has on a variety of variables (including employment and GDP) can be determined. CGE modelling differs from many modelling techniques as the results are measured as the difference between the new and initial equilibrium, usually represented as a percentage change. Also, as the modelling is carried out over a range of periods the adjustment paths of variables can be determined, allowing for a higher level of analysis.

CGE models are highly complex model with a large variation in the uses, such as economic impacts of projects (what we are using it for), taxes or productivity changes. Similar to IO modelling there will be aggregation of the sectors which is determined by the purpose of the model, dada availability and computational power. It is common for a CGE model having much less sectors that an IO model, which leads to aggregation of sectors which could be perceived as a weakness of CGE compared with IO. In the next section we look at both the strengths and weaknesses of CGE models.

5.2.2 Strengths and weaknesses

The strengths and weaknesses of CGE models has been widely discussed widely in the literature (see for example, Greenway et al (1993) and Gilmartin (2010)). This section will give an overview of both the strengths and weaknesses in general.

As has been alluded to previously the key strength of CGE models over IO models is that they introduce an active supply-side including factors of production, whereas in IO models the supply-side is said to be "passive" based solely on IO tables. With IO demand is always met by an increase in industrial output in fixed proportions (Leontief production function). However with CGE this is not always the case, as seen above there is the possibility of substitution (mainly capital and labour) depending on relative prices, leads to economy wide impacts.

McIntyre (2012) notes that the greatest strength may the micro-functions of CGE models. These are specific equations for the behaviour of firms, households and governments individually and allow for the model to be based on a consistent economic theory.

Gilmartin (2010) notes that while CGE models are based on sound economic theory and real data, they have a high level of flexibility. This flexibility makes the methodology useful for analysing the economy's response to a variety of shocks, with the results of these easily comparable to each other. Also, the different parameters, functions and closures allows for a wide range of simulations to be carried out adding to the robustness[87]. This however, can be perceived as somewhat of a weakness as CGE models are very sensitive to the closures and parameters – which must be chosen carefully. Previously we identified that elasticises are important for CGE model and as noted by Partridge and Rickman (1998) these must be chosen carefully as they can greatly impact results. It is because of this reason that the elasticises used within the AMOS are based on previous literature (Partridge and Rickman, 1998).

One documented weakness of the CGE is in the production functions, usually the 'well behaved' functions[88] – such as Cobb-Douglas, CES or Leontief – are used. These functions a relatively restrictive and may not fully represent the production behaviour (Scottish Government, 2008) but they are used to simplify the process of finding a solution. McKitrick (1998) use both compare the results from using a standard CES and another functional forms with there being noted differences in the results.

Scottish Government (2008) indicates the weakness in that the assumptions that firms minimise cost, households maximise utility and the source and direction of technology change is exogenous are partly inconsistent with empirical evidence.

Another weakness with CGE model is the assumption that the initial base year data used is in equilibrium. The SAM used for this identifies the flows of funds in a given region/country and year but it does not take into account any larger macroeconomic fluctuations (Holley, 2016). Also, similar to IO models, there is the weakness in that the base year is only a 'snap-shot' of the economy and is likely to change over time.

[87] The high level of variation in model parameters may be problematic as the model is very sensitive to these parameters.
[88] Well-behaved production functions have several key features. The first feature of these functions is that any increase in one of the inputs will result in an increase in output. Secondary for these production functions the rate of change in marginal product is negative – i.e law of diminish returns. Also well-behaved functions should be able to represent diseconomies of scale.

5.2.3 Review of CGE models and renewable energy

As would be expected – similar to IO modelling – there is a large literature in which CGE has been used a modelling platform to determine the economic impacts of renewable projects. In this section we review some of the key papers.

Both Lecca et al (2017) and Graziano et al (2017) investigate the economic impacts of UK offshore wind through the use of a CGE model. Graziano et al (2017a) use a 25 (13 energy) industry CGE model calibrated on 2010 data (UKENVI). In this paper the author's BEIS and BVG information to estimate the installed capacity and local content of UK offshore wind through 2030, with the disturbances entered as export shocks. From the simulations it is found that there are positive effects for both employment and GDP. This is the paper that is most akin to our modelling with a similar framework. One key difference is that we investigate a range of scenarios, including changes in the local content.

Two papers - Allan et al (2014) and Gilmatrin and Allan (2014) - investigate the potential economic impacts of marine energy (wave and tidal) on the Scottish economy. In Allan et al (2014) the authors use an IO model and the AMOS framework to investigate the impacts of the construction 1.6GW of marine development in the Pentland and Orkney waters. The version of AMOS used for this paper is calibrated on 2006 and has 25 sectors, although only one electricity sector. In the results there is a focus on several macro-economic impacts with the author's noting that IO overestimates employment and GVA impacts due to the passive supply side.

Again the 25 sector AMOS model was used in the paper by Gilmartin and Allan (2014) to investigate marine energy in Scotland. However, investigation was made into the cumulative impacts of all Scottish developments up to 2020 based on Sgurr energy figures. Again the characteristics of several macro-economic impacts were looked at, with particular attention paid to employment. As with the previous paper the overestimate of IO modelling was pinpointed.

Both of these paper use a similar method to that which we apply for this thesis by investigating the capacity of projects along with local content estimates. The difference again (as in Graziano et al, (2017)) is that we use an electricity disaggregated model.

Lecca et al (2017) builds on the work of Graziano et al by investigating the impact of productivity increase in the offshore wind sector. As with Graziano et al (2017) the UKENVI model was used for this purpose. In the simulation the increase in productivity is modelled as the expected change in the reduction in the levelised cost of offshore wind between 2014 and 2017 – set at 30%. Short and long run results are reported, with it being found that there will be a large increase in the total electricity use of 3.16%. Overall this increase in productivity leads to several positive effects on the economy; including lower unemployment (1.20%), higher household consumption (0.16%) and increased wages (0.14%).

Using the 24 sector CHEER model, Mu et al (2018) investigate the employment impacts of three renewable energy policies in China. The CHEER model is calibrated on the 2012 Chinese IO tables. Within the model – as is similar to AMOS version we use– the electricity sector is disaggregated by technology with a different production structure than the rest of the economy. As we will see in the next section this is similar to our model with the electricity sector having a different production function from the rest of the economy. Investigation is made into the impacts of increasing both wind and solar through three different financial instruments, Feed In Tarrifs (FiTs), Electricity Consumption Fee (ECF) and a Lump Sum Tax (LST). The authors found that the employment impacts are sensitive to both the technology and financial instrument with the solar LSF being most beneficial to employment with up to 34.1 jobs/TWh.

Other examples of CGE models being used to investigate the economic impacts of renewables, both based on biofuels, are Elizondo and Boyd (2017) and Cansino et al (2013). Elizondo and Boyd (2017) investigate economic impacts of two ethanol (for biofuels) policy simulation in Mexico. The CGE model a 2010 calibrated model with 13 production sectors. Cansino et al (2013) use a 13 sector (one-electricity disaggregated) CGE to measure the output impacts of increasing biofuel electricity in the south of Spain.

This literature illustrates that, as with IO modelling, CGE is a highly regarded framework for economic impact studies. Also as demonstrated in earlier in this chapter, due to the underlining assumptions there is a tendency for IO modelling to over-estimate impacts. In this chapter we add to the literature by modelling impacts of Scottish offshore wind through a CGE framework, which is a first (to our knowledge).

5.3 The AMOS modelling framework

In Section 5.2 a general overview of the principles of a CGE model was given, this section follows by giving detailed information on the modelling framework used in this thesis.

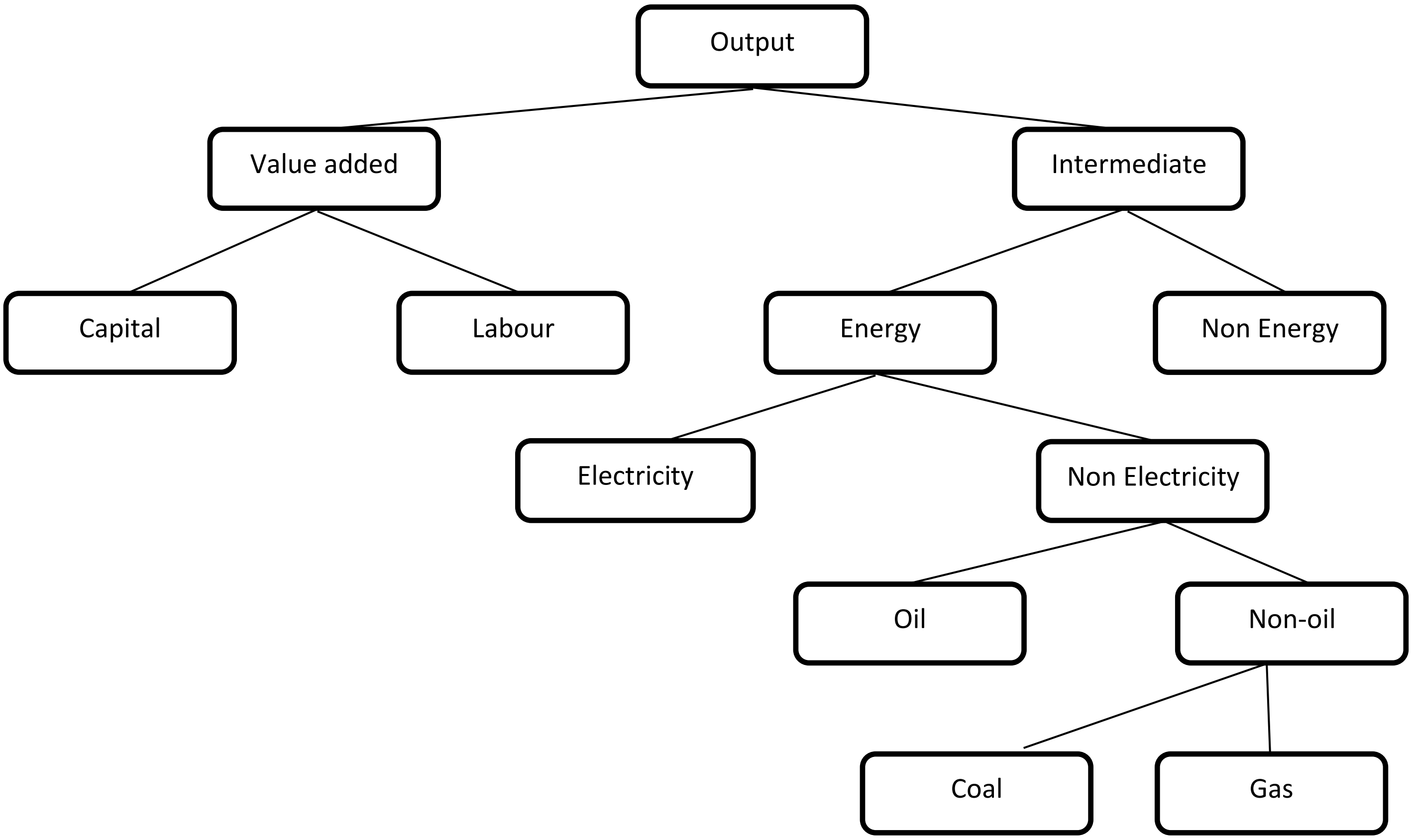
For the CGE analysis a variation of the AMOS (A Macro-Micro Model for Scotland) first developed by Harrigan et al (1991). There are several different models within the AMOS family, each with a different purpose. The version of AMOS used for this PhD has an electricity/environmental focus with disaggregated electricity sector and was initially created for investigating the environmental impacts of a carbon tax for Scotland (Allan et al, 2014b) and has been used to look at learning effects within the Scottish Marine sector (Tamba, 2012). Crucially the level of disaggregation of the electricity sector within the model made it ideal for investigating an increase in offshore wind capacity with a disaggregated electricity sector to compare with the IO carried out in Chapter 4. With our version of the AMOS initially being developed for environmental investigations there is a focus on energy with 13 of the 17 sectors related to energy, with 9 electricity generation sectors.

The AMOS model operates with disaggregated electricity sector as found in Chapter 4, all generation output is sold to a single transmissions sector which then interacts with the rest of the economy. This use of a disaggregated electricity sector distinguishes itself from other work, such as Allan et al (2014a) where an aggregated electricity sector is used.

Within the model there are 3 internal institutions (households, firms and governments) and two external, the rest of the UK (RUK) and the rest of the world (ROW). Scotland is considered as part of an open economy and it is assumed that there is no effect on international and inter-regional markets such that RUK and ROW prices are exogenous parameters.

Firms within all sectors are set to be cost minimisers, with each identified by a CES production function with a nested structure. Two different production structures are used within the model, one specific to the electricity supply sector and another to represent the other 16 sectors within the economy. Figure 5.3 below shows the standard non-electricity production structure with the electricity supply structure found in Figure 5.4.

Figure 5.3 Schematic of production structure of 16 sectors within AMOS model.



Source Allan et al (2014b)

Similar to the standard nested structure found in Section 5.1, the total output of each sector is a combination of value added and intermediate inputs. Value added is both the labour and capital inputs while intermediate are both energy and non-energy inputs. There has been debate within the literature on whether energy is part of the intermediate or value added nest[89], in the AMOS model energy is part of intermediate inputs. This energy CES function is further split into electricity and non-electricity with the latter an aggregate of oil and gas. As previously outlined a fundamental assumption within this model is all electricity generation sectors all sales are to the transmission sector, thus in the production structure for the 16 sector all electricity input are from transmission. As electricity transmission has inputs from the different generation the production structure is slightly different found in Figure 5.4

[89] Lecca et al (2011) discuss in detail, where energy should enter the production function.

Figure 5.4 Schematic of production structure of electricity supply sector within AMOSENI model. Source Allan et al (2014)

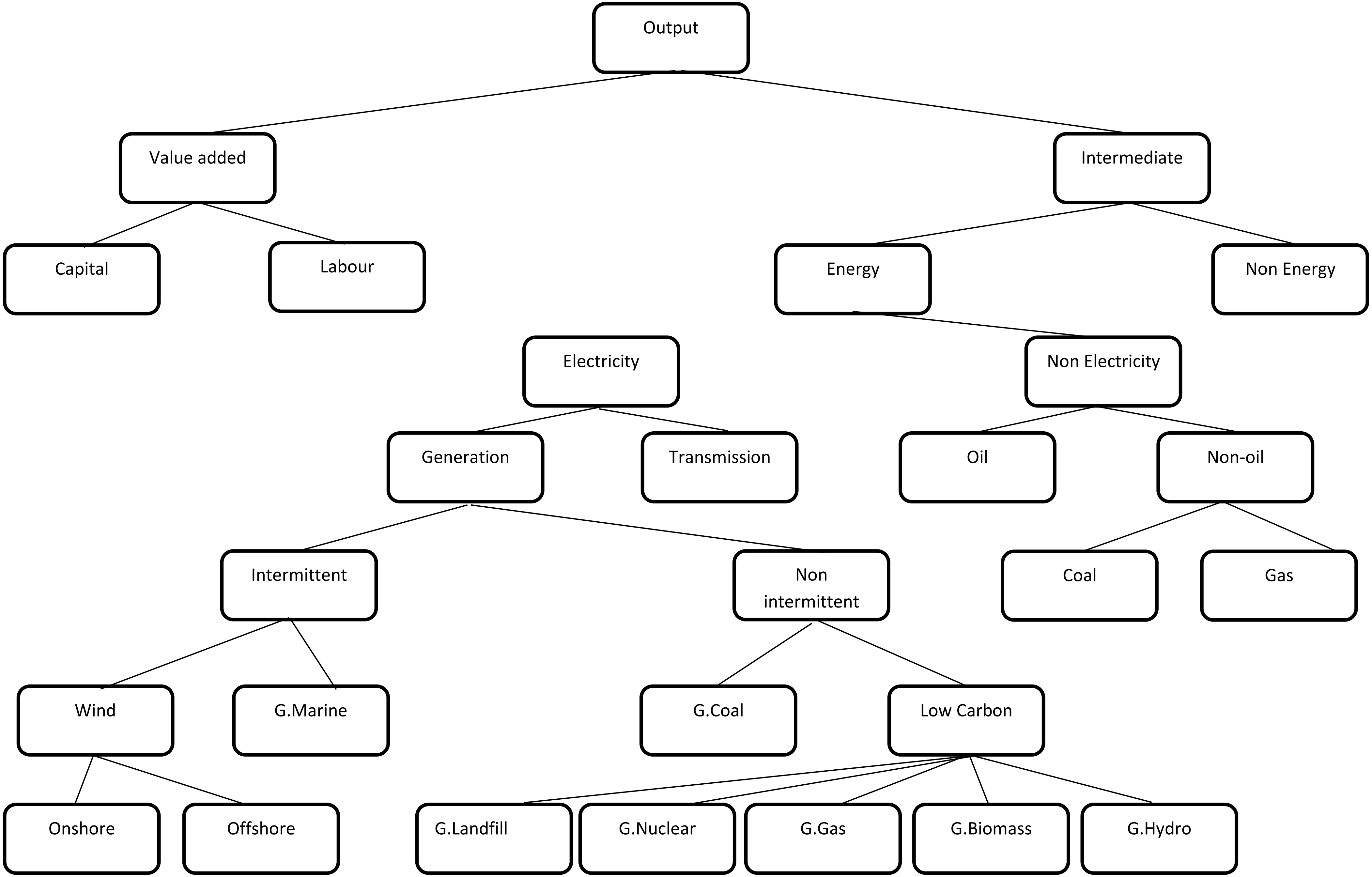

Output
Value added
Intermediate
Capital
Labour
Energy
Non Energy
Electricity
Non Electricity
Generation
Transmission
Oil
Non-oil
Intermittent
Non intermittent
Coal
Gas
Wind
G.Marine
G.Coal
Low Carbon
Onshore
Offshore
G.Landfill
G.Nuclear
G.Gas
G.Biomass
G.Hydro

Figure 5.4 shows the structure of electricity transmission is similar to other 16 sectors with a multi-level CES function, the major change is that the electricity nest is further separated. Electricity is a combination of intermediate and non-intermediate generation functions with each being made up of different technologies. The intermediate function has both onshore and offshore wind along with marine renewables while non-intermediate has 7 technologies: coal, gas, pumped hydro, nuclear, marine and biomass. This structure allows for substitution between similar technologies as explained in Section 5.2.

In the model it is possible for the firms to source intermediate inputs locally or import from the rest of UK (RUK) or rest of world (ROW). Region sourced inputs can be substituted for imported goods and are combined in the production structure as an Armington CES function – which treats the substitution as imperfect.

Important for the simulations are the elasticities of substitution within the CES production functions, found in Table 5.1 below.

Table 5.1: Elasticities of substitution used in AMOS.

Nod	**Elasticity**
Intermediate – Value added	0.3
Energy – Non Energy	0.3
Electricity – non electricity	2
Oil – non oil	2
Transmission – generation	0.3
Intermediate – non intermediate	5
Between non intermediate	5
Wind – marine	5
On – offshore wind	5
Between non-energy	0.3

Source: Tamba (2014)

For most of the CES functions the elasticity of substitution is set to a default 0.3, with all of deviations from this occurring in the energy inputs. Between electricity and non-electricity the value is increased to 2, with the same being done for oil and non-oil. As explained in Tamba (2014) these elasticities greater than 1 are used to reflect the higher flexible substitution between fossil fuel energy and electricity generation. Between the electricity generations the elasticity is set even higher at 5 indicating there is a possibility of substitution of between technologies. The same product (electricity) is being produced by a range of technologies and it is easy to substitute between each[90].

The AMOS model is highly flexible framework with there being several different closures available. It is possible for the model to be run in either in "myopic" or "forward-looking" expectation. The main difference between these closures is that under the myopic condition agents have adaptive expectations meaning that they only react to present prices, while in the forward looking case firms and consumers have perfect foresight and react to anticipated future events (Allan et al, 2014a). The long run in the framework is set to 50 periods.

In Lecca et al (2013) the differences between these expectations are described in detail, with illustrative results from a model with both given. The author's note that under certain circumstances the long results are the same – which contradicts some of the earlier literature. While the long run results may be the same (similar) the author's note that the transition paths differ, driven mainly by the way in which investment and consumption decisions are made.

Investment decisions within the forward looking AMOS framework are modelled based on Hayashi (1982) whereby the rate of investment is a function of the ratio of the value of firms to the replacement cost of capital. In the framework the path of investment is modelled as:

$$Max \sum_{t=0}^{\alpha} \frac{1}{(1+r)^t} [\pi_t - I_t(1 + g(x_t))] \qquad (5.1)$$

Here a firm is maximising cash flow from a given profit π, private investment I_t and adjustment cost $g(x_t)$. However, in the myopic expectation the investment are set as a fraction

[90] Not accounting for the different principle of operations of technologies.

of the gap between the desired and actual (adjusted for depreciation) level of capital stock – in line with the Jorgenson (1963) neoclassical investment formulation.

Consumers, under the forward-looking expectation, maximise the present value of a utility using the following life-time utility function (Allan et al 2014b).

$$U = \sum_{t=0}^{\alpha} (\frac{1}{1+\rho})^{t} \frac{C_t^{1-\sigma}-1}{1-\sigma} \qquad (5.2)$$

The consumption at time t is C_t with σ the elasticity of marginal unity and ρ the constant rate of time preference. Budget constraints ensure that the present value of consumption does not excess household wealth. In the myopic expectation, with no perfect foresight, consumption is a linear function of disposable income.

As previously identified there are several closures available within the AMOS model relating to the labour market and migration, with are the same for both forward-looking and myopic. Migration can be either turned on or off in the model. When migration is 'off' there is no change in labour supply. However in the 'on' migration case the labour force is free to move, and this is determined by the wage rate. The AMOS model has been calibrated on the information found within Layard et al (1991) and the equation below.

$$LS_{Scotland} = LS_{t-1}(1 + m_{Scotland}) \qquad (5.3)$$

In the on migration case at each time period the labour force (LS) updates according to Equation 5.3. This change in labour force is completely attributed to migration ($m_{Scotland}$) as there is no change in the natural population. Migration to Scotland is determined by the gap between the regional and national unemployment rates as well wages and consumer price index. This is characterised in the model by:

$$m_{Scotland} = \sigma - \ 0.08[\ln(u_{Scotland}) - \ln(u^{UK})] + 0.06\left[\ln\left(\frac{w_{Scotland}}{cpi_{Scotland}}\right) - \ln\left(\frac{w^{UK}}{cpi^{UK}}\right)\right] \qquad (5.4)$$

Here σ is a calibration parameter to ensure zero migration in the base year. In the equation the migration is negatively correlated to the gap between the logs of Scottish ($u_{Scotland}$) and UK

(u^{UK}) unemployment. Whereas migration is positively related to the gap between log regional ($\frac{w_{Scotland}}{cpi_{Scotland}}$) and national ($\frac{w^{UK}}{cpi^{UK}}$) real wages[91]. As migration in AMOS is based on the work by Layard (1991), the elasticises are set at -0.08 for the employment gap and 0.06 for the real wage gap.

Within the model there is the possibility of two different wage rate closure – fixed and regional bargaining (again the same for both forward-looking and myopic). In fixed wage rate the wage specification does not change with disturbance. For the regional bargaining case the wage rate and unemployment are inversely related according to Equation 5.5 below.

$$\ln\left(\frac{w_{Scotland}}{cpi_{Scotland}}\right) = c - 0.113 \ln(u_{Scotland}) \qquad (5.3)$$

In this equation c is a calibrated parameter while w_t is the nominal wage with $cpi_{Scotland}$ being the consumer price index and u_t unemployment. From equation 5.3 the real wage is indirectly related to the log of unemployment with an elasticity of -0.113 – from Layard (1991).

These closure demonstrate one of the advantages of CGE over IO modelling as they allow for a much more detailed analysis of shocks. In the IO the economic impacts are determined by the size of the shock and industrial relationships found within the IO accounts (the A matrix). However, with CGE there are many more variable affecting the overall impacts – especially prices, and the response of firms and consumers to these changes.

5.3.1 Updating the AMOS model dataset

The original AMOS model was calibrated on information from a 2000 Scottish SAM. However, the economy (especially the electricity sector as seen in Chapter 1) has changed dramatically over time, which has to be acknowledged in the modelling for this thesis. Thus

[91] $w_{t,}$, u_t and CPi_t are non-time varying

the model had to be updated to 2012. This was done by creating an AMOS usable Scottish SAM for 2012, in a similar manner as that detailed in Emonts-Holley et al (2014).

SAMs are considered to be an extension of the IO tables which give a more comprehensive picture of the economy (Miller and Blair, 2009, Chp 11). In the IO table payments to factors of production (wages, other value added) are given however there no payments to institutions (i.e households, governments, corporations). With the SAM the linkages between the institutions and the rest of the economy are recorded thus a more complete picture.

As previously identified a SAM is generated through incorporating the information found within income expenditure accounts with IO tables. The IO table used for this was the electricity disaggregated table from Chapter 3, whereas the 2012 Scottish income expenditure account was developed using arrange of data sources.

Income expenditure accounts are developed to detail the flows between different institutions within the economy (Household Corporations and Governments) as well as for Capital and External sectors. Including this information with IO tables gives a fuller picture of the flows within the Scottish economy.

Following the methodology outlined by Emonts-Holley et al (2014) several publically available data sources aided in the development of the 2012 income expenditure account. These included the 2012 Scottish IO table, GERS figures, ONS blue hand-book. The full income expenditure account used for the SAM development can be found in Appendix 5A.

As identified earlier the AMOS has 9 electricity generation sectors, whereas the base IO tables from Chapter 5 only has 7 which includes an 'other generation'. For the model to run, a disaggregation of this 'other' generation into biomass, landfill and marine based on BEIS (2013b) information.

5.4 Modelling strategy

In Section 4.4 the scenarios simulated using IO methods are given, using the AMOS model these scenarios were simulated (a reminder of these is listed below). The CGE model allows for calculation of overall macroeconomic impacts as well as the changes in a higher level of variables (% changes and time varying). Also we can compare the results of the IO and CGE models to show the difference in the approach.

Scenario 1: The ‘generic’ 588MW Scottish offshore wind farm. In Chapter 4 this scenario 1 was run to investigate the effects of an individual wind farm using and IO framework. In the IO simulation only effects on output, GVA and employment were measured, whereas using the AMOS framework more detailed analysis can be carried out.

Scenario 2: Planned increase in Scottish offshore wind capacity. There is due to be a large increase in Scottish offshore wind in the near-future which is likely to not only affect the demand-side but also supply, which is accounted for in the AMOS framework.

Scenario 3a and 3b: Two longer term scenarios – gradual (3a) and accelerated (3b) – investigating economic from potential growth in Scottish offshore wind.

As with the IO modelling these shocks will be introduced in the model as an external demand shocks by sector, with the demand calculated using the developed model from Section 4.4. Initially this model was developed to shock each sectors from the 23 sector IO however with the CGE modelling only having 17 sectors an extended aggregation was required. Appendix 5B gives the aggregation from the full Scottish IO tables to use in the CGE.

In the IO framework expenditures are input directly as the absolute changes in value, however the AMOS framework requires these to be input the relative change format (i.e the size of the shock, by sector, compared with base year exports) . These calculations were carried out using the demand shocks and the export information available from the Scottish SAM. Also in Chapter 4 we find the bridge matrix which converts the project expenditures into SIC codes – and in this we find that there are expenditures allocated to the electricity sectors. Using the

AMOS framework[92] these expenditures needed to be relocated to the manufacturing and services sectors.

Found in the previous section the AMOS allows for different closures to be applied, with these being applied to each scenario.

With the simulation strategy applied determined the results all three scenarios is detailed below.

5.5 CGE modelling results

With the introduction of an active supply side with price variation, CGE modelling allows for a higher level of analysis than the IO modelling in Chapter 4. In this section we investigate a range of effects from the different scenario simulations.

5.5.1 Scenario 1 - Low content

As with the IO modelling the first simulation which was carried out was for a single wind farm, for both high and low content. The advantage of modelling only one wind farms is that the long term (legacy) effects of a single farm can be identified – which is not the case with IO modelling. Also within CGE modelling there is much more measured variables which can be analysed. With the CGE model the single wind farm has been modelled in both a myopic and forward looking closure. The discussion below evaluates the results in turn, starting with IO then myopic and finishing with forward-looking

[92] As the AMOS was originally developed to model environmental changes, when the electricity distribution sector experiences a large demand shock there is an unrealistic change in output from generation technologies – especially gas . Thus to overcome this, the expenditures were relocated to the manufacturing and services sectors. Also the primary assumption in the model is that all generation only sells to the distribution meaning there is no exported demand and the costs need to be moved.

5.5.1.1 IO

As previously identified IO modelling is a special case form of a CGE with several underlining assumptions – most notably the passive supply side. With this passive supply side the economic impacts within IO modelling are directly related to the demand shock and only occur when these are present – as can be found in Figures 5.5 and 5.6.

In the simulations of a single wind farm there is a 6 year demand disturbance (periods 1-6) for CAPEX followed by a 25 constant demand disturbance for the OPEX. Once these disturbances stop the economic impacts stop i.e no legacy effects.

5.5.1.2 Myopic

Unlike with IO modelling, in the myopic simulation there is an active supply side along with price variations which allow for a higher level of impacts to be determined. With myopic simulations the agents react to the demand shocks and prices and have no future foresight.

From Figure 5.5 the most obvious point of note is that the GPR impacts under the myopic closure are much less during periods 1-6 than the IO closure. Under the myopic closure, GPR peak is only £32.07 million compared with the £119.74 million for the IO simulation. The key reason for this – with the active supply side – is that there are crowding out of some sectors. In Figure 5.7 and 5.11 both the prices and wages have increased which reduces the competitiveness of sectors (i.e there is crowding out occurring).

Unlike in the IO simulation where there is a large drop off in the GRP impacts once the O&M stage starts (period 7), the myopic GRP does not peak until 7. This occurs as in the myopic simulation there has been a large build of capital stock (Figure 5.10). After the demand disturbances stop there is still positive GRP 'legacy' effects due to the build-up of capital stock.

In Figure 5.6 we again find that the scale of employment during the CAPEX stage is much greater for the IO simulation than the myopic. The peak for the myopic is 1,006 reached at period 6, 2 periods after the peak demand shock. With no future foresight the myopic simulation is reacting to the demand shocks and between periods 4-6 there is a slight reduction in the demand shocks but they are still significant in value. In Figure 5.7 it can be found that CAPEX demand shocks increase wages, which is explained later in this section.

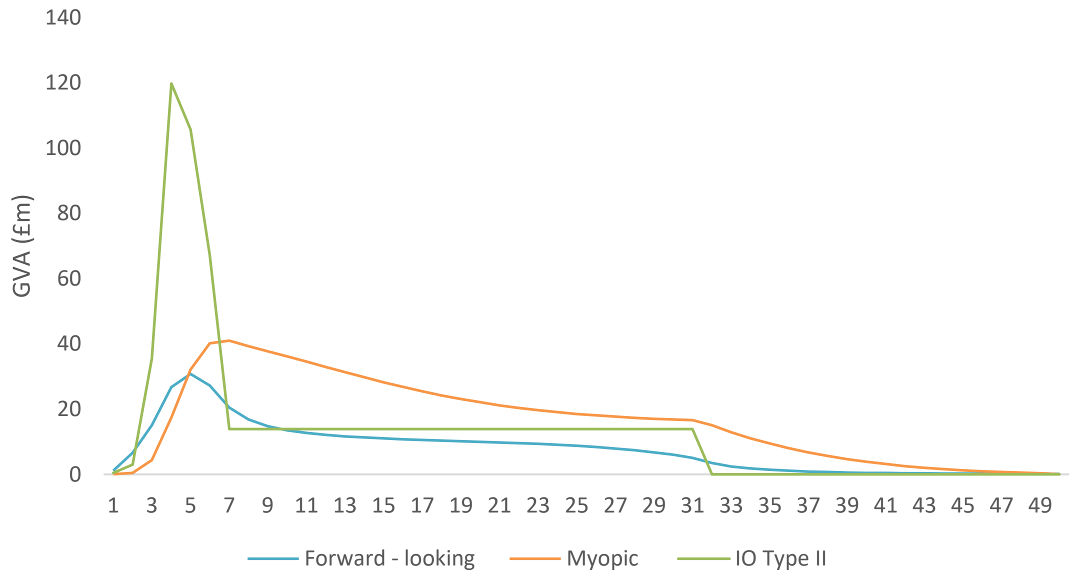
Once the simulations move into the O&M stage (period 7) we find that the employment in the myopic simulation is now larger than that for the IO simulations. Thus occurs as the myopic (unlike IO) simulation is reacting to the supply-side and price as well as the demand disturbance As found in Figures 5.7 and 5.8 there is a larger labour supply but the wages are lower than the reference year (2012). After period 31 – the last demand shock –there are still some employments effect, knows as the 'legacy effects' until equilibrium is met at period 40. These effects are occur as during the periods of shocks (especially construction) there has been a build-up of capital stocks which will be depleted until equilibrium but still produces positive effects.

During the construction stage of the project both the real and nominal wages are found to increase, as would be expected. At this time there is a squeeze on employment and thus the employees are able to bargain for higher wages. Once construction is finished though (period 6) we find that there is a sharp fall in the wage rates, indeed they become lower than in the initial period. With the increase in labour supply there is more employees than required and the wage rate drops as employees cannot barging for higher wages at this stage. These wages also affect the labour supply demonstrated in Figure 5.8. Under the myopic closure we find that after period (31) there is a further reduction in the real wage due to the demand disturbances reducing further.

With migration allowed within the model the labour force will flow to a region if the wage rate is higher than the national rate. In Figure 5.8 we find this to be the case for the offshore wind project, the labour supply sees a large increase during the construction stage reacting to the large increase in wage rate (Figure 5.7). Labour supply peaks in one period (7) after the construction stage. The peak does not occur during the construction stage as there are still significant demand shocks and the average wage larger than the references year thus the migration is still reacting to this, not expected the reduction in period 7. After period 7 there is a significant reduction in the labour supply as out migration occurs due to the decrease in wages below the reference year. Once the demand disturbances stop there the labour supply reaches equilibrium again at period 50 (which is the imposed equilibrium point from the modelling).

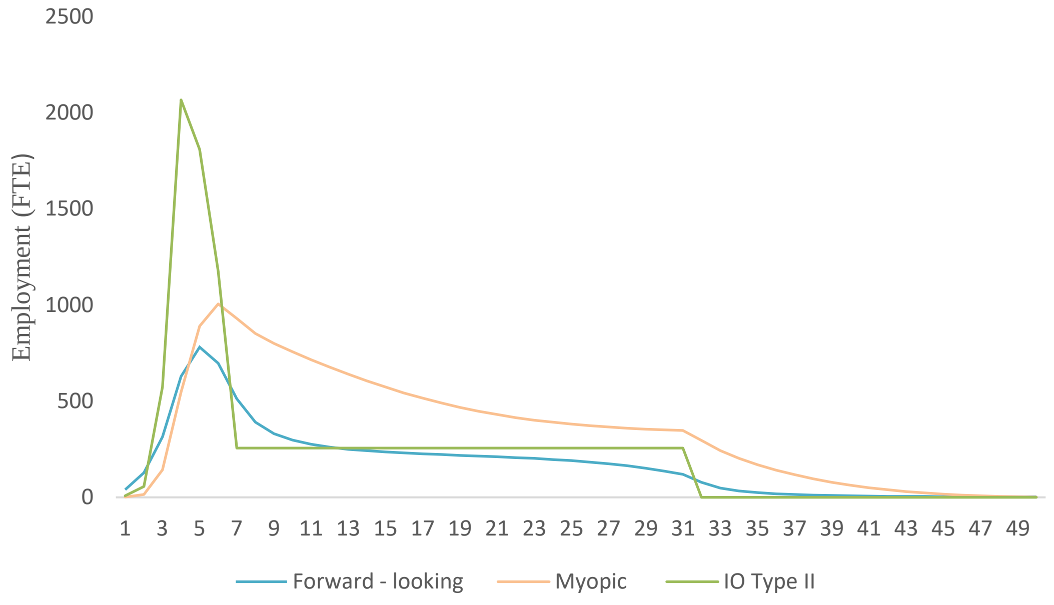
In the myopic case the level of consumption (Figure 5.9) is related to household spending power. During the construction stage of the project, there is a large increase in the household consumption, occurring due to the wage increase demonstrated in Figure 5.7. At the O&M stage of the project when the wage rate drops there is as a decrease in household consumption, however due to the lower CPI at this stage (Figure 5.11) reduction this is a steady decrease. Once the demand shock decrease there is a steep consumption decrease to equilibrium as the wage rate has decreased further.

Figure 5.5: Low content GVA/GRP for single offshore wind farm.



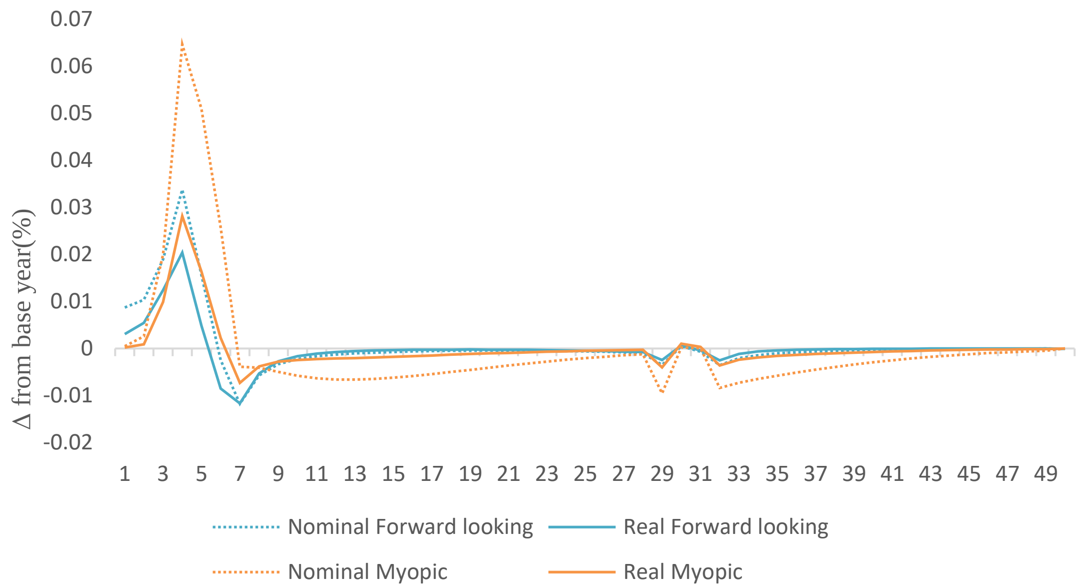
Source: Author’s calculation

Figure 5.6 Low content employment for single offshore wind farm.



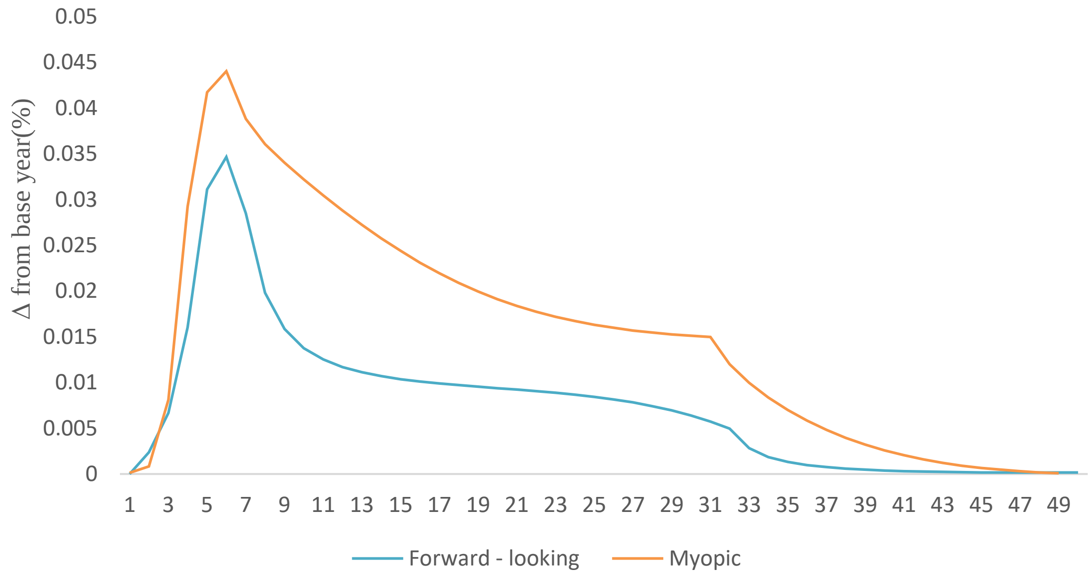
Source: Author's calculation

Figure 5.7 Low content wage rate variations with single offshore wind farm.



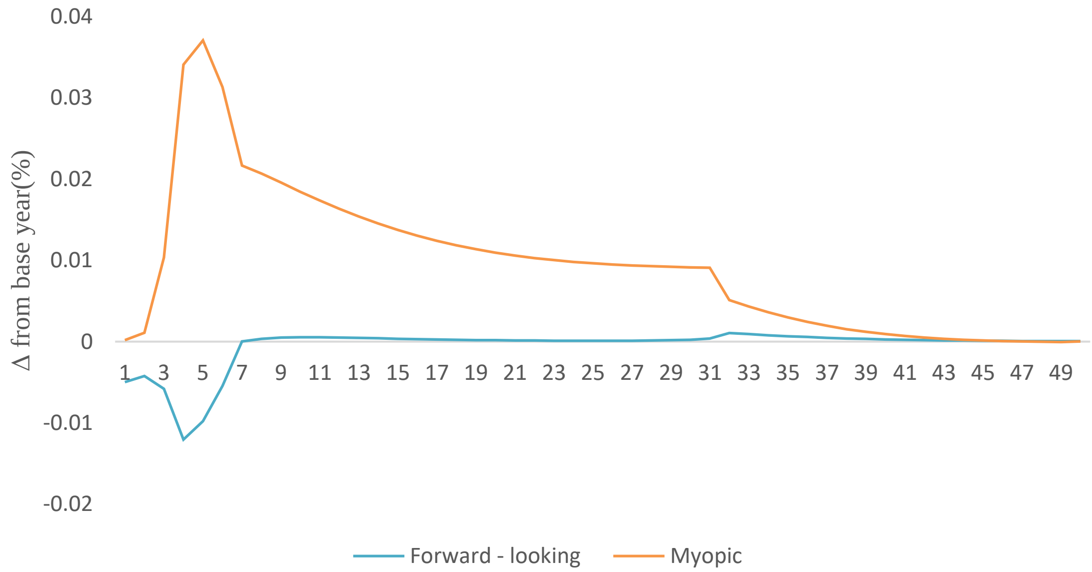
Source: Author's calculation

Figure 5.8 Low content labour supply variations with single offshore wind farm.



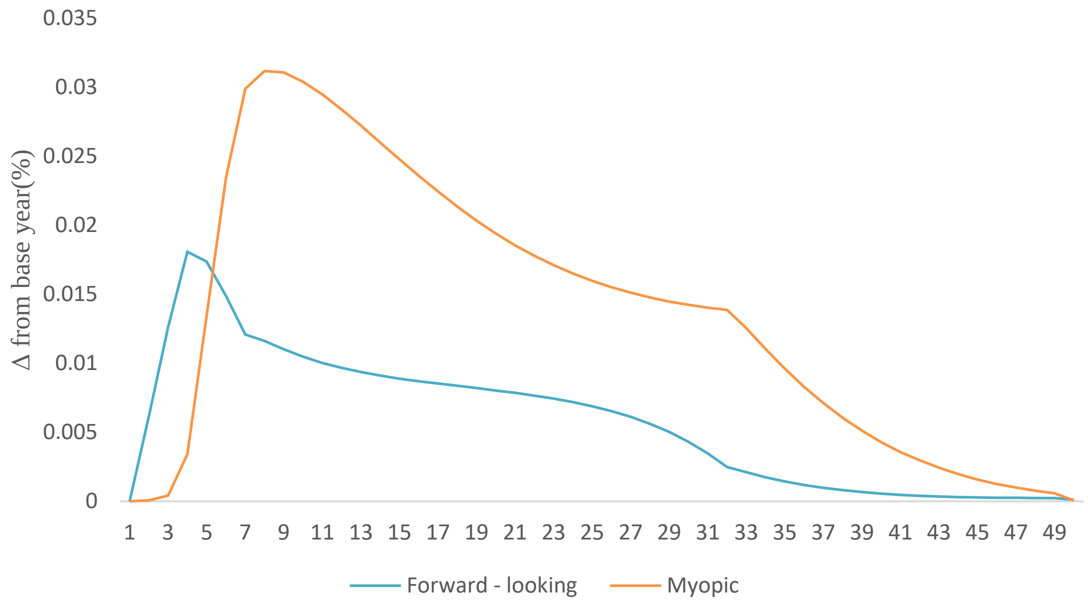
Source: Author’s calculation

Figure 5.9 Low content household consumption variations with single offshore wind farm.



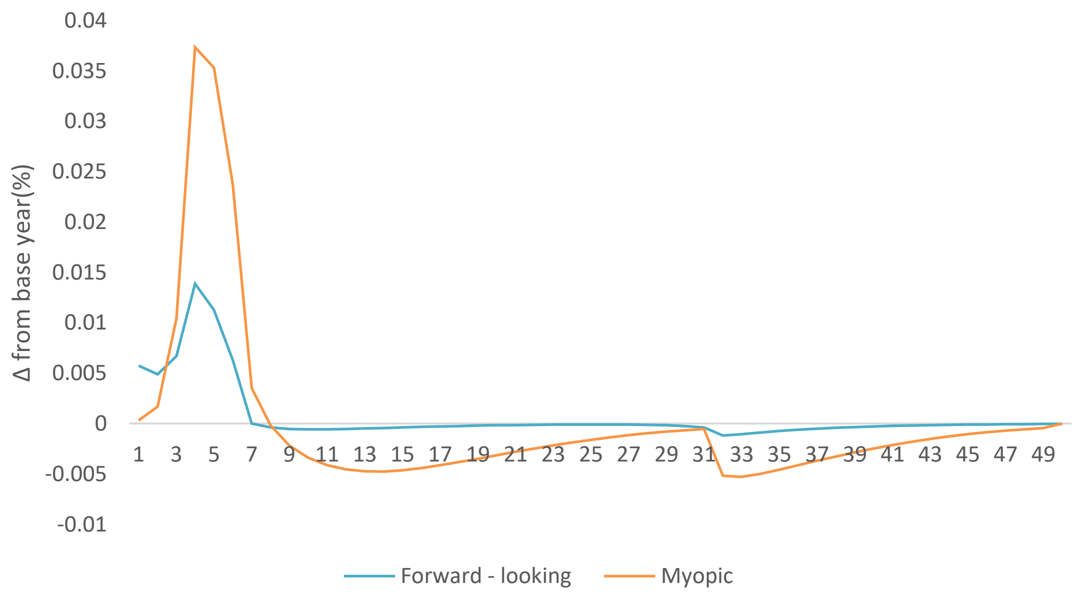
Source: Author’s calculation

Figure 5.10 Low content capital stock variations with single offshore wind farm.



Source: Author’s calculation

Figure 5.11 Low content CPI variations with single offshore wind farm.



Source: Author’s calculation

5.5.1.3 Forward-looking

The difference between a myopic and forward looking closure is than rather than being reactive, forward looking agents in the model know future prices, impacting on investment and consumption decisions.

The peak of GPR occurs under forward looking (period 5) is much closer to the peak demand shock at period 4. With the increase in demand and prices expected at earlier periods, earlier investment is made in capital stock in the forward-looking simulation, effecting GRP. Also, the increase in capital stock is lower in the forward-looking case, adding to smaller GRP legacy effects.

Forward-looking employment impacts (Figure 5.6) follow a similar pattern to the GRP in that the impacts are lower than myopic at all periods. During the construction stage there are two main drivers behind this smaller impact. Firstly, the changes in prices are known thus there is an expectance of only a temporary demand. Secondly, from Figure 5.10, during the periods of peak demand disturbances (4-5) the forward-looking capital stock (which can be substituted for labour) is larger than myopic.

In the forward-looking case the pattern for wage rates is similar with the scale being different (Figure 5.7). During the construction stage there is less of a wage bargaining with the expected drop in prices. Whereas after the construction stage the forward-looking wages drop further than the myopic. Figure 5.8 shows also that the migration effects are lower in the forward-looking case due to the lower wages,

While there similarities in the time-path of some variables with forward-looking and myopic closures of the CGE model, there are some with major difference. One such being household consumption (Figure 5.9), which with myopic agents is a function of disposable income. Forward-looking agent consumption however, is based on the knowledge of future price to maximise utility (as identified in Equation 5.5) and as a result the time-path is unlike that of the myopic case. With this forward looking case the households foresee the large increase in Consumer Price Index (CPI) (Figure 5.11) during construction stage thus reduce their consumption. While the CPI during the construction stage has little change reflected in the household consumption. CPI then reduces below the initial value after the project has ended and at this time we find an increase in the household consumption with the lower prices – maximising their utility.

During the construction stage of the project there is a large increase in the demand for products thus pushing up overall prices within the economy. Again the forward-looking smaller than myopic due to the expectation of the reduction in demand shocks. At the O&M stage in the forward looking closure the prices remain stable while at the myopic prices reduce below base value increasing gradually. In both closure after the shocks are stopped (period 31) there is a reduction in prices – due to the build-up in stock - which as with the other variables reaches equilibrium by period 50.

As well as the overall impacts, CGE modelling allows for sectoral impacts to be investigates as we find in the next section for the high content scenario 1 simulations.

5.5.1.4 Totals (NPV)

With the use if CGE and IO modelling we are able to compare the NPV[93] of the cumulative employment and GVA impacts in present value, found in Table 5.2.

Table 5.2: NPV impacts of a single (low content) wind farm.

	GVA (£m)		
	Construction	Operation	Total
Type 2	*293.0*	*192.3*	*485.3*
Myopic	*82.05*	*405.8*	*487.8*
Forward looking	*92.35*	*161.8*	*257.1*
	Employment (FTE)		
	Construction	Operation	Total
Type 2	5,031	3,544	8,575
Myopic	2,267	8,384	10,650
Forward looking	2,293	3,584	5,887

Source: Author's calculation

[93] As with Chapter 4 a discount rate of 3.5% was used.

In Table 5.2 we have split the cumulative employment impacts into two distinct periods – construction and operation. There are some very noticeable differences depending on the closure of the model.

During the construction stage (were the demand shocks are large) we find that the IO model than both the GRP and employment impacts are much greater in the IO model than the CGE. The calculated GVA impact using the IO model are more than double (£293 million) when compared with the myopic and forward-looking CGE closures, £82.05 million and £92.35 million retrospectively. Employment impacts at the construction impacts are 5,031 person years (IO), 2,267 person years (myopic) and 2,293 person years (forward-looking).

As identified previously - with fixed prices and a passive supply side – the IO model impacts are directly related to the magnitude of the demand disturbance. However in the CGE model, the characteristics of the economy (prices, labour supply) along with the demand shock have an effective supply side. These limit the impacts on both the employment and GVA during this construction stage. These results are in line with Allan et al (2014a), which indicates that for the construction stage of renewable projects IO models typically overstate impacts.

The impacts from the myopic and forward-looking closures differ during the construction stage, even though both use the CGE framework. With the forward-looking closure employment and GVA impacts larger. This occurs as with foresight the forward-looking closure increases the employment and capital stock in expectation of the increase in demand, whereas myopic is reacting only in the period when the demand is implemented.

While during the construction stage IO modelling has the largest GRP and employment impacts, the opposite is true for the operation stage of the project with IO having the lowest effects. During the construction stage there is substantial decrease in the demand shocks which feeds directly through to the GVA and employment impacts at each period. However, with the active supply side, in the CGE models there has been a build-up of capital stock and labour supply (along with changes in prices) which impact the reaction to the reduction in demand.

Unlike the construction stage, during operation of the wind farm impacts are larger in the myopic case compared with the forward-looking. Again, the key reason behind this is the forward-looking expectation of the reduction in demand disturbances after period 6.

In this section we have looked the overall effects of a single (low content) offshore wind farm, following from this is investigation into sectoral impacts.

5.5.1.5 Output Changes in stimulated and non-stimulated sectors

As with IO modelling, using a CGE model allows for sectoral impacts to be identified. In this section we investigate the sectoral output changes for both stimulated and non-stimulated sectors under the myopic closure.

In Figures 5.A and 5.B, we find the changes in output for the stimulated and non-stimulated sectors respectively. As would be expected in the myopic case with the stimulated sectors there is increased output during both the construction and O&M, when there is increased demand.

Figure 5.12: Myopic stimulated sector output.

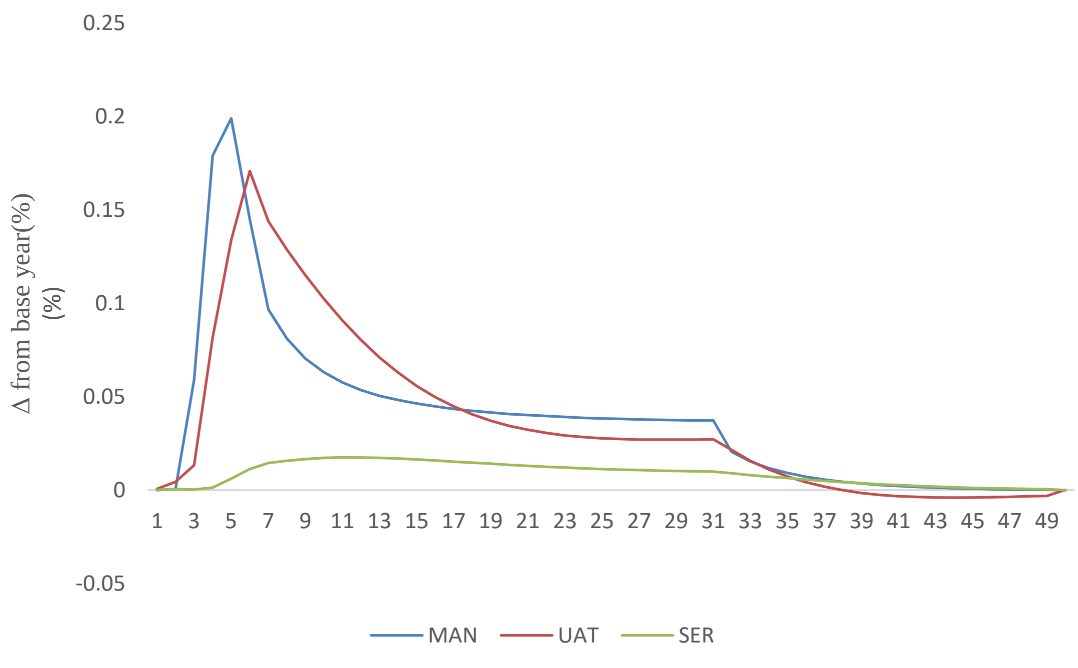
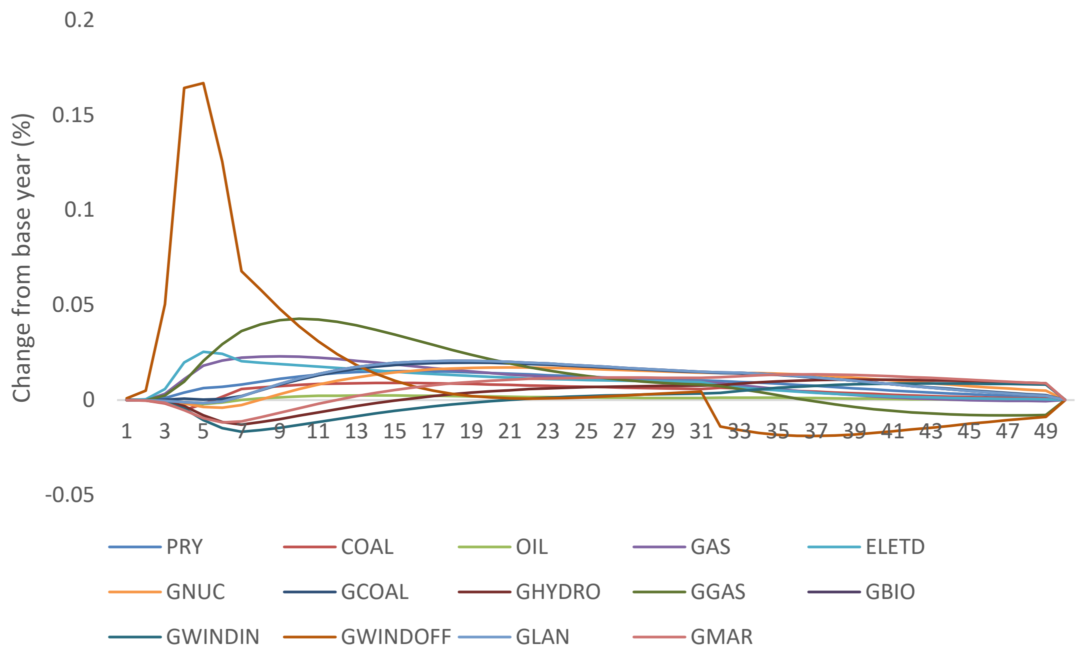


Figure 5.13 – Myopic non-stimulated sector output.



Source: Author's calculation

Figure 5.12 demonstrates that during the construction stage there is a much greater increase in the manufacturing output (>0.15%) than the services sector (<0.01%). A key reason for this is at this stage – according to the bridge matrix – much of the construction is focused on manufacturing and transports sectors. Also the change in output of the services is much less as the base output (from the SAM) is much larger (more than 4 times) than both other sectors.

During the O&M both the outputs of manufacturing and utilities and transport decrease, while the output of the services increase. Again according to the bridge matrix most of the O&M expenditure is through the services sector, thus there is an increase in output. We find that the reduction in manufacturing is much steeper than that of utilities and transport, driven by the larger reduction in manufacturing demand. Finally, once the demand shock finish, all three sectors output reduces to equilibrium – with utilities and transports output actually lower than base year between periods 38 and 49.

The output of the non-stimulated sectors is determined by the linkages to the stimulated sectors and as found in Figure 5.13 there are both positive and negative impacts for these non-stimulated sectors. Initially there are only two non-stimulated sectors (primary and offshore wind) which see an increased output with the other 12 having a reduction in output at period one. The reduction in these sectors is cause, as explained earlier, by the increase in CPI and wages at these time periods reducing competiveness and causing crowding out effects. Gradually as the output of the stimulated sectors increase, the output of each of the non-stimulated increases. The output of each non-stimulated sector increases to a level greater to base year during either the construction of O&M stage of the project. As with the stimulated sectors, once the demand shocks stop, there is a convergence to equilibrium with some sectors at point seeing a having a smaller output than the base year.

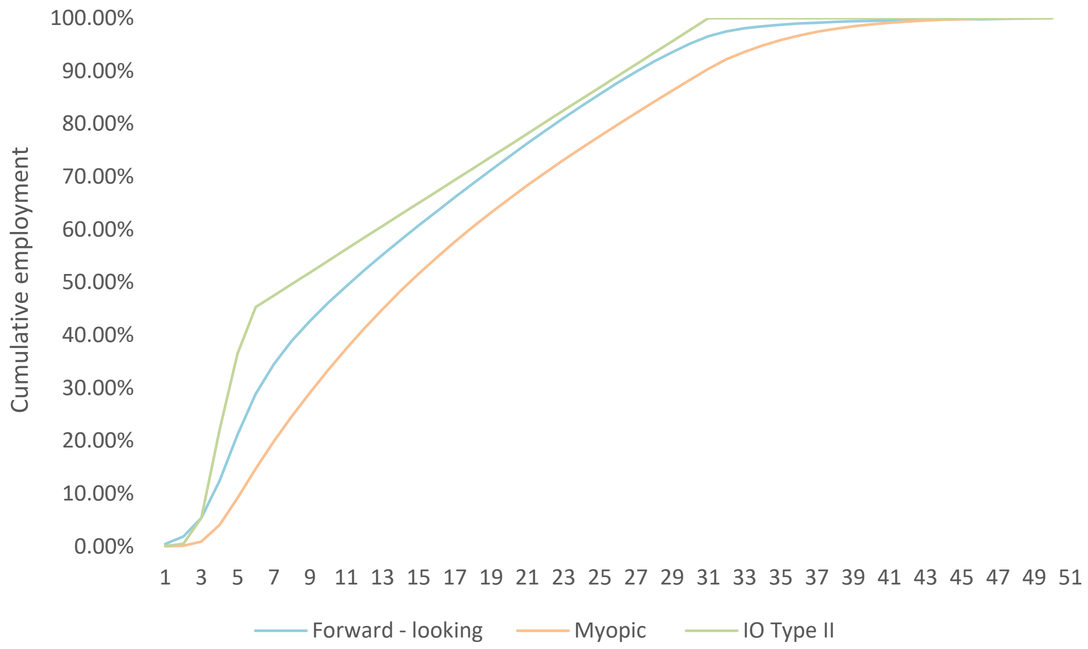
A final point of note from Figure 5.13 is the scale of changes in the offshore wind sectors. We found that the scale of change in the services sectors was small due to the large output of the sector, the opposite is true for the offshore wind sector. Due to its small output, even small changes in output can cause a large percentage change.

5.5.1 Scenario 1 Single offshore wind farm – high content

In the modelling we modelled both the low content and high content scenarios for the single offshore wind. When varying the content the only change is in the scale of the expenditures to each of the stimulated sectors, which means if we compare the time path of impacts with that of the low content they are very similar. It is the size of the impacts which are different. As the time paths are similar we do not include these in this section – they can be found in Appendix 5C

In the single wind farm high content scenario we identify the cumulative employment impacts, which are found in Figure 5 below.

Figure 5.14: Single wind farm cumulative employment impacts.



Source: Author's calculation

This figure reinforces the point that IO modelling is driven by the expenditures, which with steep increase during the construction stage of the project accounts for more than 45% of all employment impacts. During the O&M, with the IO model, there is a steady increase in cumulative employment matching the constant expenditure shocks and 100% of employment impacts are reached by the end of the projects.

In both the myopic and forward looking the cumulative employment impacts are much less by the end of the construction case, 14.74% and 28.87% retrospectively. The forward looking impacts are greater stage are greater at this stage as foresight of future prices and changes in demand are known, whereas myopic is reactive. After the construction stage, again due to the foresight, forward looking impacts increase at a greater rate than the myopic case.

As with the low content case we calculate the NPV of GVA and employment impact for the high content case, with the results below.

Table 5.3: NPV impacts of a single (high content) wind farm.

	GVA (£m)		
	Construction	Operation	Total
Type 2	*345.1*	*243.6*	*588.7*
Myopic	*98.8*	*493.0*	*591.82*
Forward looking	*114.0*	*201.0*	*315.0*
	Employment (FTE)		
	Construction	Operation	Total
Type 2	5,932	4,490	10,422
Myopic	2,728	10,200	12,927
Forward looking	2,748	4,447	7,196

Source: Author's calculation

As is to be expected with an increase in local content (i.e expenditure) there will be an increase in both GVA and employment impacts.

5.5.2 Scenario 2 Planned capacity – high content

In Chapter 4 we simulated the economic impacts of Scottish offshore planned capacity, which we do again in this Chapter, but this time using the AMOS framework – both with low and high content. As with the single wind farm the low and high content impact time paths are similar thus in this section we only focus on the high content results, with low content graphs found in Appendix 5.

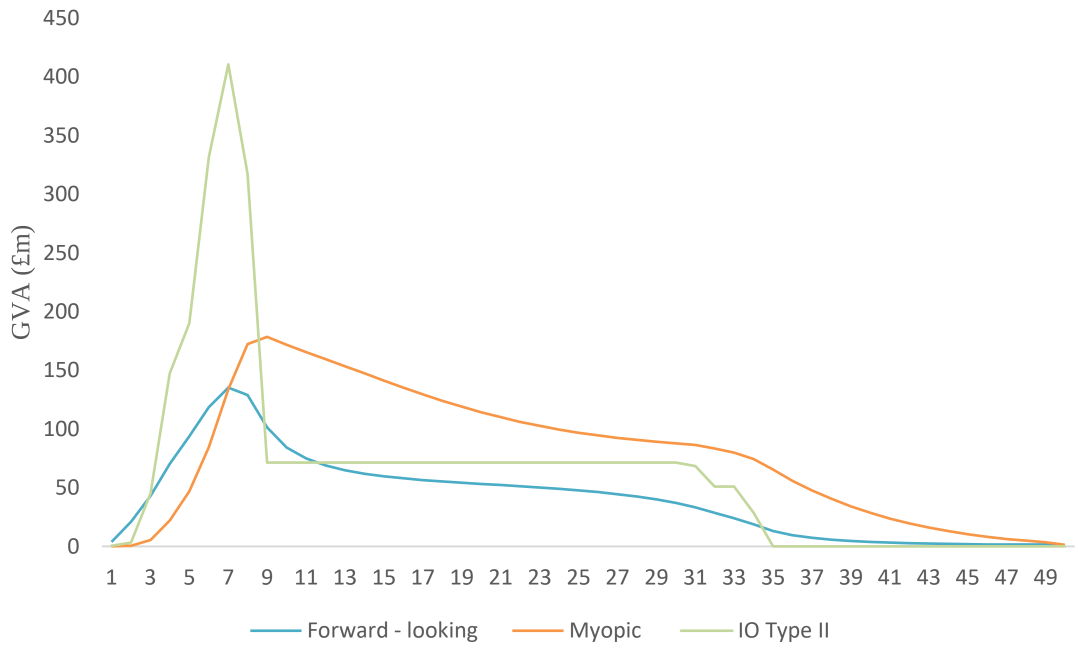
The evolution of impacts in this simulation are very similar to that found for the single wind. With each of the wind farms being build quick succession (between a 5 year period) there is a large expenditure during the first 10 years of the simulation (similar to the single wind farm construction stage) followed by an extended period of O&M expenditure until period 30 which reduces gradually as the lifetime of projects is reached.

From Figures 5.15 and 5.16 we find again, similar to Scenario 1, that the IO GVA and employment impacts are much greater than the myopic and forward-looking. Both GVA and employment peak at period 7 (the largest expenditure) whereas the myopic case GVA peaks at period 9 and employment period 8 with both forward-looking peaks at 7. Again this occurs due to the investment and consumption of agents and the build-up of capital stock.

During the first 7 period of the simulation we find from Figure 5.17 that there are fluctuations in the wage rates, although they are always greater than the base. In the myopic case the real wage rate raises in steps until period 8, from which there is a large drop off in period 9 due to the excess in labour supply. The forward looking case there is a slight reduction in wages between periods 4 and 5, and after period 7 there is significant reduction in wages with the excess labour supply (Figure 5.19). Similar to the single wind farm both the myopic and forward-looking real wage rates recover to near equilibrium during the O&M stage, with reductions again seen after this stage and equilibrium reached at period 50.

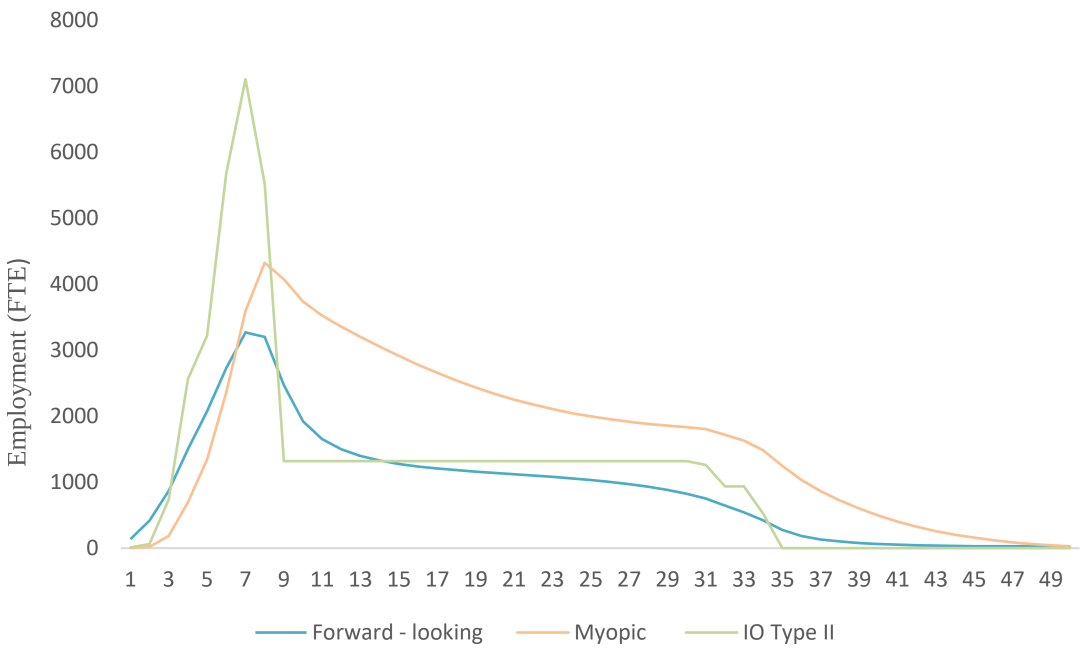
In this planned capacity we find that the household consumption again differs in both cases. As with the single wind farm in the myopic case with increased disposable income household (Figure 5.18) increase their consumption during the construction which gradual decreases during the O&M stage till equilibrium. While in the forward looking case households maximise utility by reducing consumption at times of high cost (construction) and increasing with lower prices – after period 30.

Figure 5.15 – Planned capacity (high content) GVA.



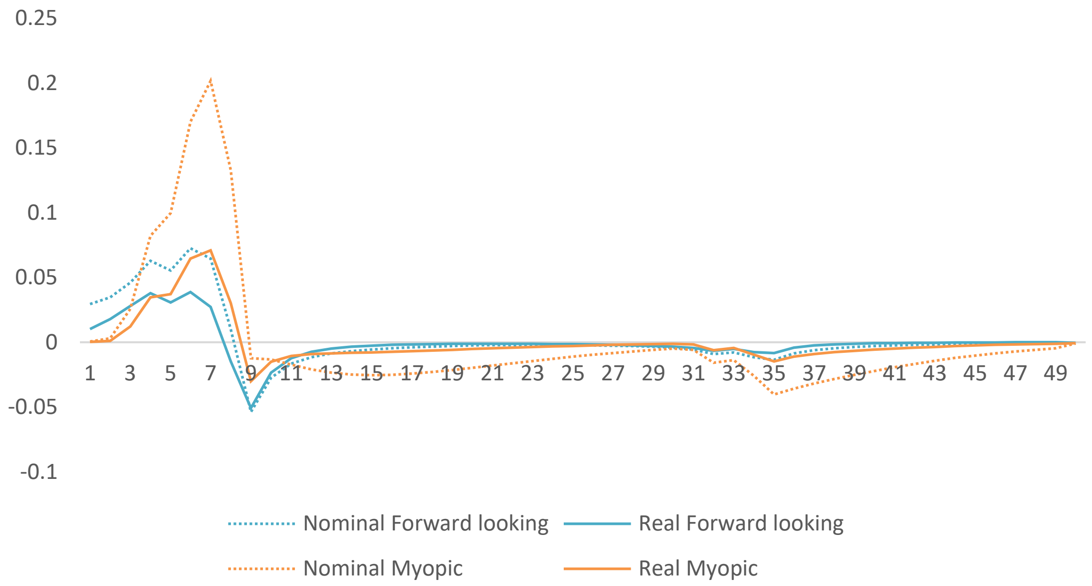
Source: Author’s calculation

Figure 5.16 – Planned capacity (high content) Employment.



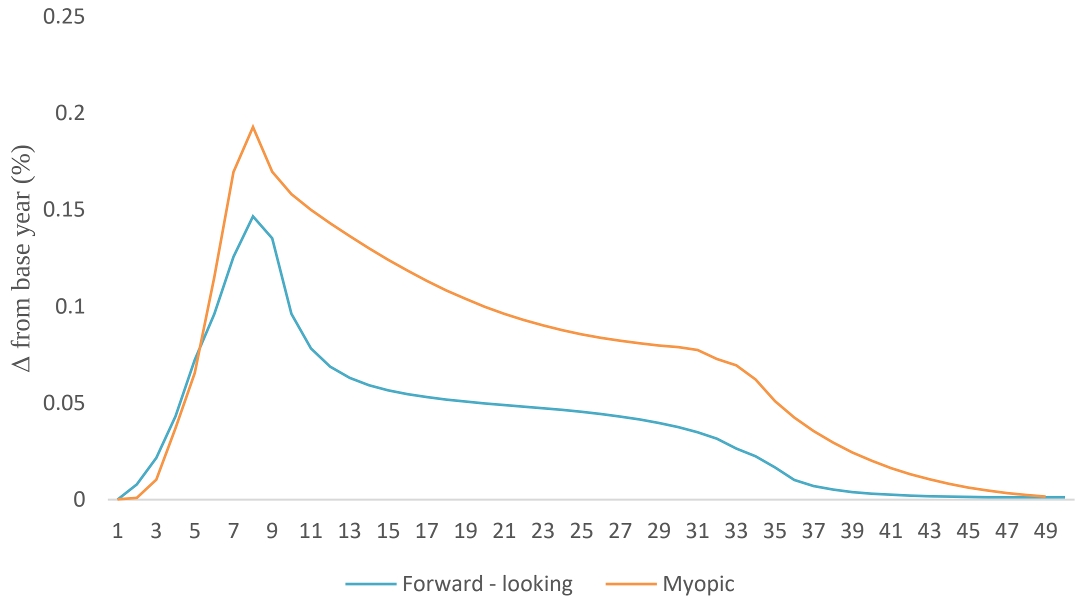
Source: Author’s calculation

Figure 5.17: Planned capacity (high content) Wage rate.



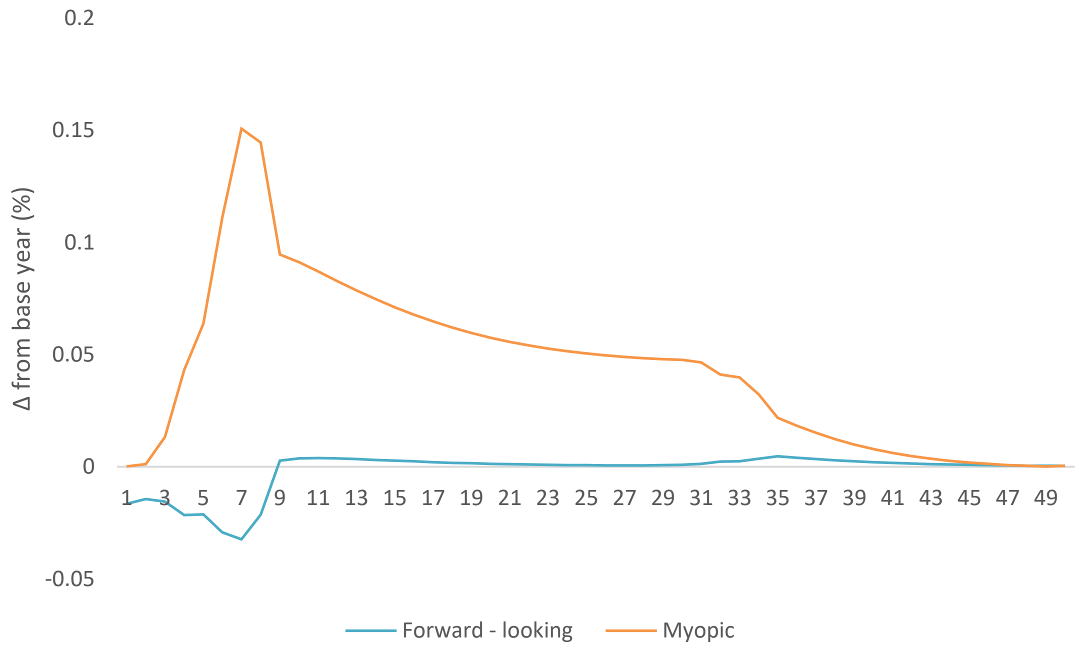
Source: Author's calculation

Figure 5.18 – Planned capacity (high content) labour supply.



Source: Author's calculations

Figure 5.19 – Planned capacity (high content) Household consumption.



Source: Author's calculation

As with previous simulations we give the NPV of the planned capacity simulations in Table 5 – both low content and high content.

Table 5.4: Planned capacity NPV employment and GVA.

Low content		
	GVA (£m)	Employment
Type 2	1743.6	30,861
Myopic	1855.0	40,560
Forward looking	1072.5	24,179
High content		
Type 2	2126.6	37,708
Myopic	2137.6	46,712
Forward looking	1288.7	28,819

Source: Author's calculation

For both the GVA and employment we find that in the myopic case has the highest impacts followed by IO and then forward looking. As has been identified in IO modelling there are clearly larger impacts during the construction stage of the projects. But as they are driven by expenditure these reduce dramatically in the O&M stage and there are no ‘legacy’ effect. With the CGE modelling there are also other factors driving the changes in the economy thus there is a gradual reduction in impacts during the O&M stage. Forward-looking, with foresight, does not increase employment or capital stock to as high a level as myopic during the construction stage and as such lower impacts. However, in the myopic case, there is a large increase in both capital stock and employment during the construction stage and this scale coupled with the longer time to reach equilibrium leads to larger impacts than IO.

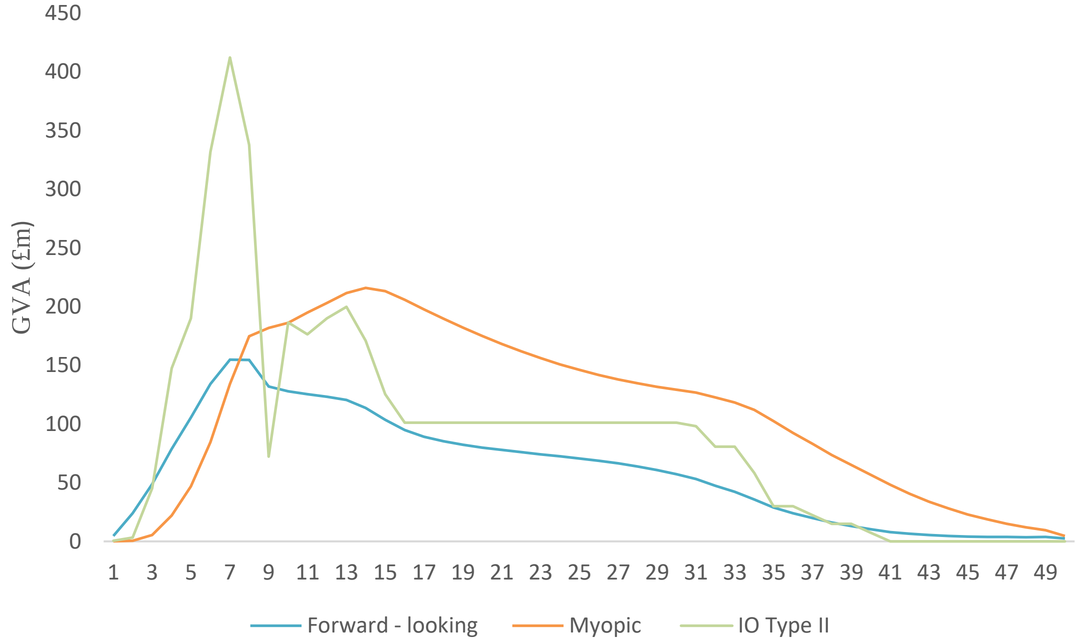
5.5.3 Scenario 3a and 3b Planned capacity with growth

The final simulations that were carried out were to measure the economic impacts from potential growth in Scottish offshore wind capacity after 2025. Scenario 3a is a growth of an extra 1GW by 2030 of capacity and 3b 2GW of capacity, with both simulations having low and high content simulations. Again the time paths of these simulations are similar thus we will only focus on one of the simulations – high content gradual growth – with the results for the other simulations

Investigating Figures 5.20 and 5.21 we find the time paths are similar to the previous scenarios with large growth in impacts during the first 15 years of the simulations (the construction period), followed by a gradual reduction at the O&M stage and finally a convergence to equilibrium (CGE) . The most distinguishing factor from these figures is the IO impacts with large variations caused by the changes in expenditure. Again we find that forward-looking impacts, due to the foresight of temporary shocks, are lower than both IO and myopic.

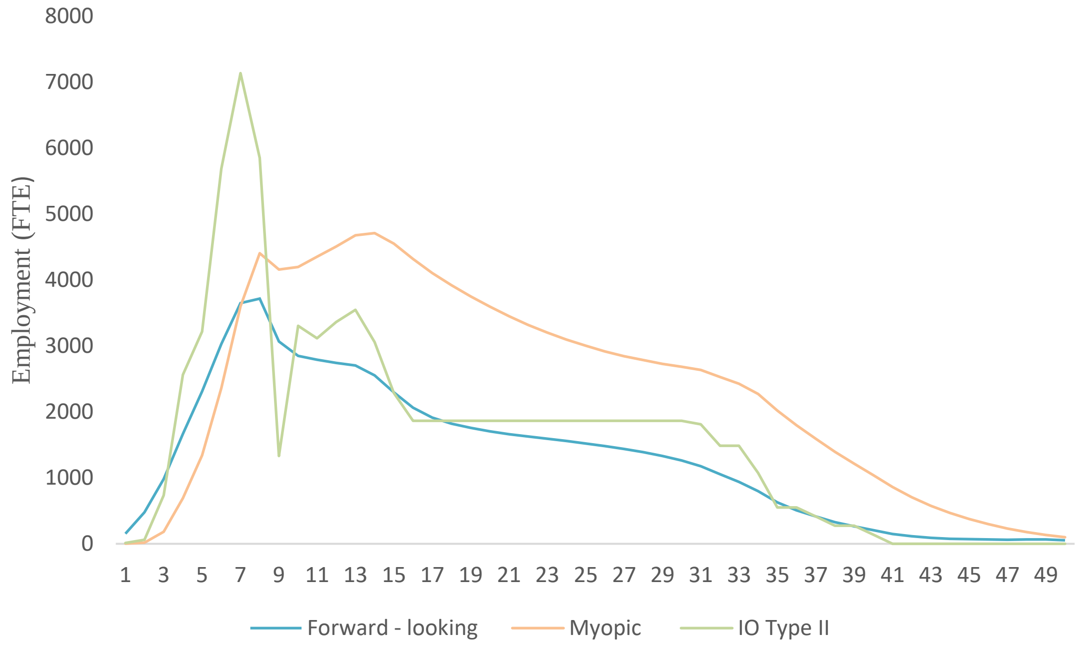
Figures 5.22, 5.23, 5.24, 5.25 give the wage rate, household consumption, capital stock and cpi retrospectively. The time-paths of these variables are similar to the first two scenarios, with the reasoning for these covered extensively above. As such we do not detail them as much as the scale of impacts is the fundamental difference.

Figure 5.20: Planned capacity gradual growth (high content) GVA.



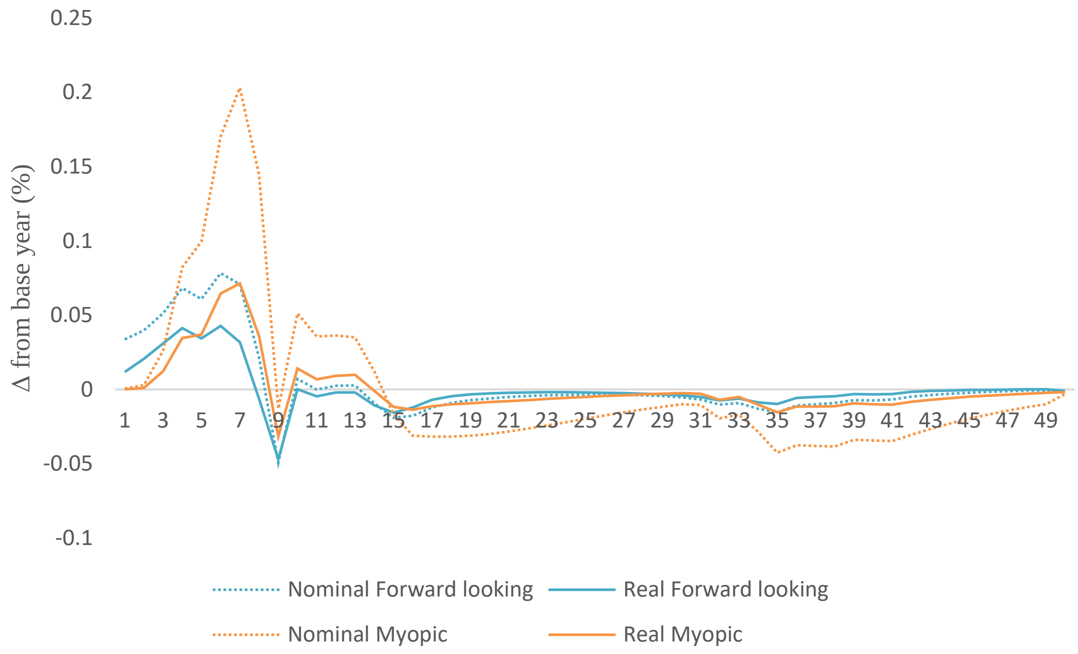
Source: Author's calculation

Figure 5.21: Planned capacity gradual growth (high content) employment.



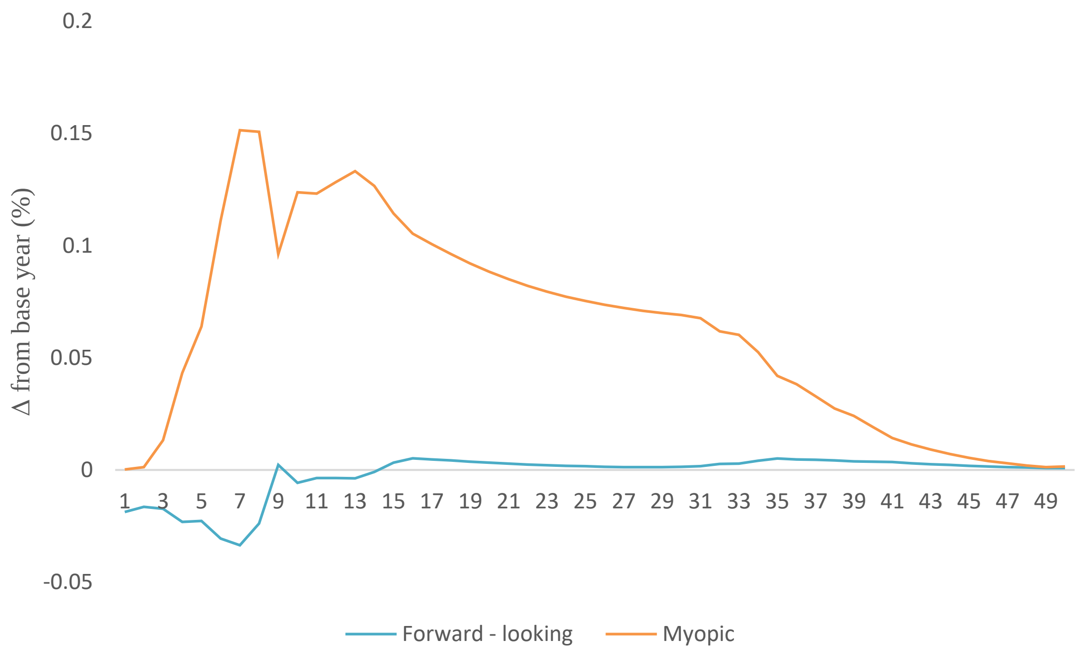
Source: Author's calculation

Figure 5.22: Planned capacity gradual growth (high content) wage rate.



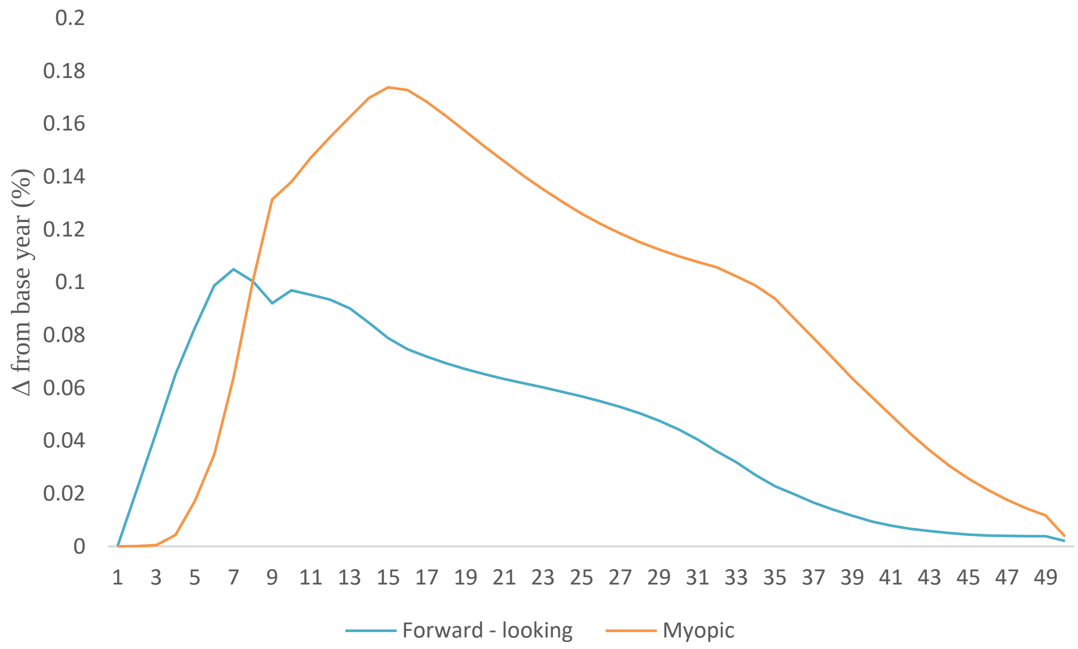
Source: Author's calculation

Figure 5.23: Planned capacity gradual growth (high content) household consumption.



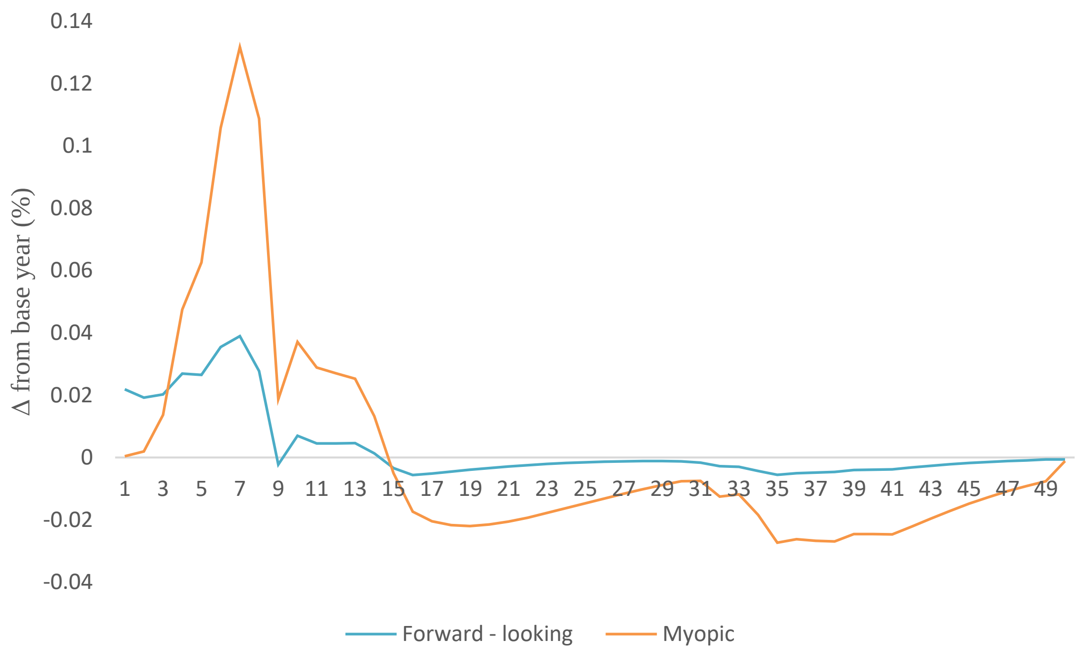
Source: Author's calculation

Figure 5.24: Planned capacity gradual growth (high content) capital stock.



Source: Author’s calculation

Table 5.25: Planned capacity gradual growth (high content) CPI



Source: Author’s calculation

There are however significant changes in the aggregated NPV GVA and employment, which are contained within Table 5 below for all simulations in these scenarios.

Table 5.5: Planned capacity with growth NPV employment and GVA

Gradual growth				
	Low content		High content	
	GVA (£m)	Employment	GVA	Employment
Type 2	2366.4	41,930	2882.8	51,156
Myopic	2357.0	51,493	2867.2	62,666
Forward looking	1488.0	33,000	1825.7	40,486
Accelerated growth				
	Low content		High content	
	GVA (£m)	Employment	GVA	Employment
Type 2	2989.2	52,999	3639.0	64,405
Myopic	2951.6	64,491	3576.5	78,191
Forward looking	1931.8	42,636	2345.4	51,793

Source: Author's calculation

We find that the increase of offshore wind capacity and the related expenditure in Scotland will have substantial benefits for the economy. In our modelling we have estimated that a growth in capacity to 2030 could increase GVA between 2.05% and 3.14% and employment 1.42% and 3.38% of base year values.

As explained in the previous chapter in the timeframe of this modelling, through the development of the supply chain, there is likely to be increasing in local content. Thus the estimates in this scenario can be thought of as minimum values.

5.6 Conclusion and limitations

This chapter has extended the analysis of the economic impacts of Scottish offshore wind development found in Chapter 4 through the use of a CGE framework. To our knowledge this is the first time this framework has been used for this purpose and allows for a more in-depth analysis on the overall economic effect of increasing Scottish offshore wind capacity. CGE builds on the work IO framework by relaxing some of the key assumptions allowing for - active supply side, price variations, labour change and substitution through non-Leontief production functions.

In Chapter 1 we found that there has been a recent shift in Scottish energy policy, with economic development being identified as crucial along with emissions reductions. With the development of Scottish offshore wind there is expected to be substantial expenditure within Scotland, which will bring economic impacts. Previously we modelled these economic impacts through a use of an IO model and found that the results were exclusively positive – due to the model being entirely demand driven. With the CGE modelling however we find that, at certain periods in the modelling, there will be some negative impacts such as an increase in unemployment rate and a reduction in real wages. While at times there is the possibility of negative impacts overall, using the CGE methodology, we find that there is an increase in both employment and GVA with an increase in Scottish offshore wind capacity. This chapter has also highlighted the usefulness of CGE models for policy makers as a higher level of impacts are modelled, allowing for a clearer picture of economy wide impacts.

For our assessment of the potential impacts Scottish offshore wind we used the AMOS family of CGE frameworks, with our particular model focused on the electricity sectors. The original AMOS model was calibrated on 2000 data and as such for the purpose of continuity with the rest of this PhD was updated to 2012 through the development of a 2012 SAM. This again shows the usefulness of the Scottish ElSA, as we use this to disaggregate the IO table which is a key input to the SAM (the other being the income expenditure account). The AMOS framework allows for several different closures, our modelling is based on free migration with wages determined by regional barging in either a myopic or forward-looking closure.

We simulated the same scenarios as we use in Chapter 4 with both low and high local content. The CGE model allows us to explore many more economic impacts including: GVA, employment, prices, unemployment rate, labour supply, wages, household consumption, investment and capital stock. Much of which are unidentifiable through the use of a standard IO model. While there are a range of results, there are parallels to results found within Allan et al (2014a) in that IO models have a tendency to overstate impacts. We find in our simulations that is particularly pertinent at the constructions stage of the offshore wind projects where there is a large portion of overall expenditure – the IO GVA and employment impacts are much larger than both CGE closures.

In Allan et al (2014a) the focus was solely on the construction stage of projects were there are large expenditures. In this chapter we have also included the O&M stage of projects and find that at this stage the IO impacts are actually lower than the myopic CGE simulations at times, in contrast with Allan et al (2014a). The reasoning behind this, as explain previously, is that CGE impacts are driven by more than just expenditures thus there is a build-up of capital stock and labour supply during the construction stage which takes time to fall back to equilibrium.

The key contribution of this chapter is that we have used a CGE framework for analysis of the potential economic impacts arising from the development of Scottish offshore wind capacity. This is the first time (to our knowledge) that this framework has been used for this purpose, with all current economic impacts assessments using an IO framework. The use of the CGE framework allows for the impacts of a larger amount of variables– such as wages and prices – to be determined, which can only be advantageous to policy makers.

In the next chapter we give overall conclusions to this thesis along with future work potential.

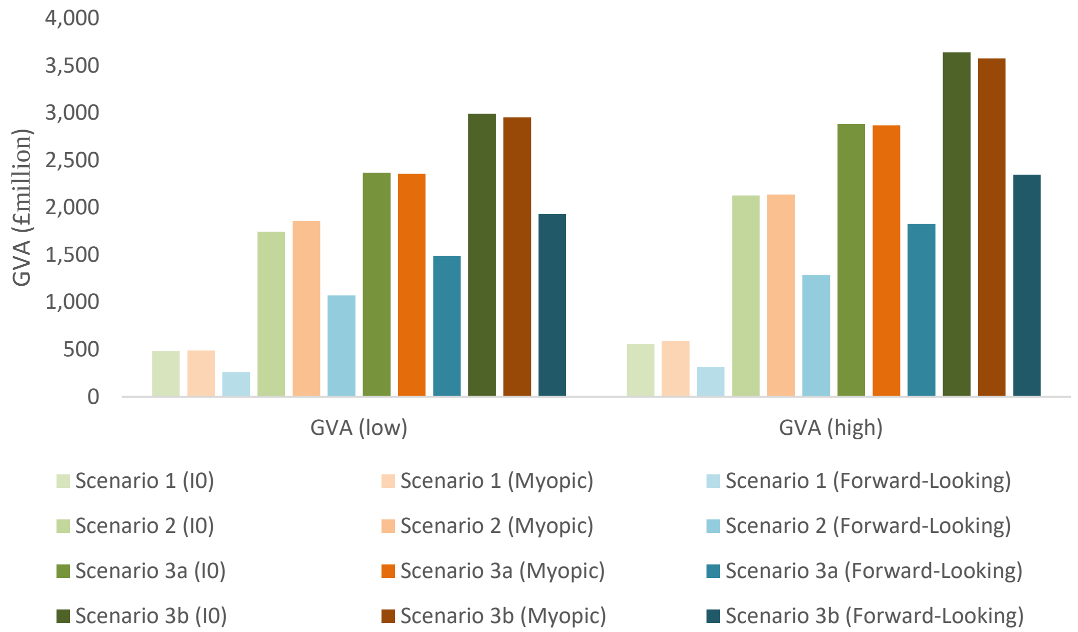
Chapter 6 – Thesis conclusions and future work

6.1 Chapter summaries and contributions

A key objective of recent Scottish energy policy is to reindustrialise Scotland through renewables (Scottish Government, 2011a) and with Scotland having 25% of all European resource wind (Scottish Government, 2011a) offshore wind is key in this reindustrialisation. The development of offshore wind will have economic impacts on the local economy (in terms of GVA and jobs) and there is the potential for this expertise to be exported. Even with such an abundance of offshore wind resource the development of offshore in Scotland wind has been slow with only one current fixed offshore farm in operation. There are a number of reasons for this, including technical issues and environmental opposition. With many of these issues resolved, there is the expectation that we will see a significant increase in Scottish offshore wind capacity in the near future with several offshore wind farms either under construction or consented.

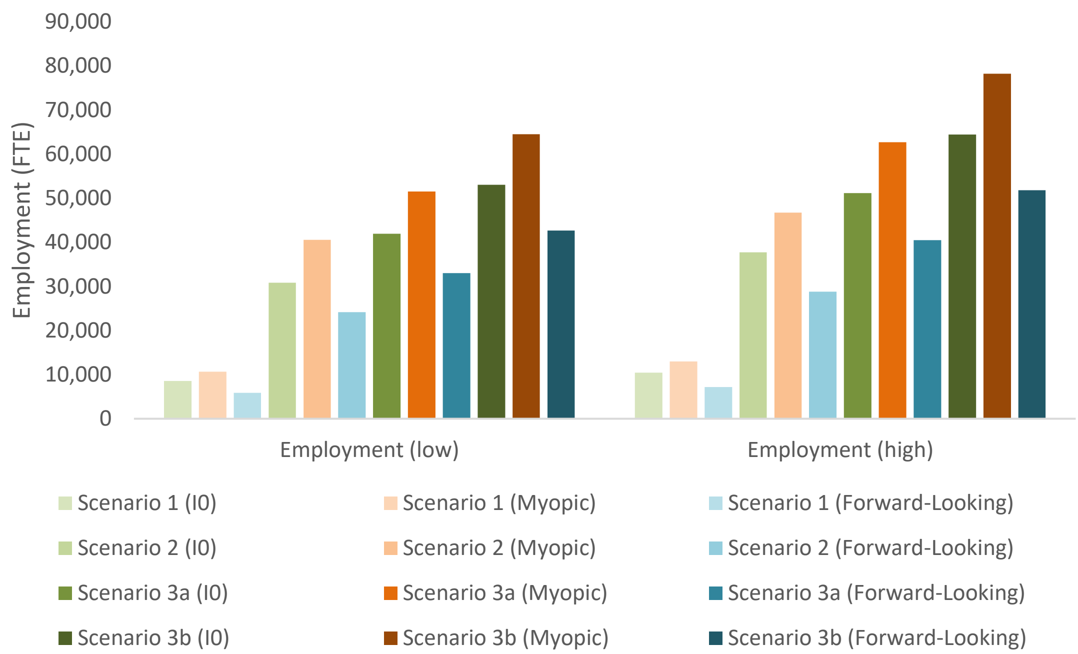
The primary output of this PhD thesis is to assess the potential macroeconomic impacts resulting from an increase in Scottish offshore wind developments. Currently there are some reports measuring the impacts of individual wind farms using an IO framework (Beatrice offshore wind Ltd, 2017; FAI, 2017). In this thesis we take both an IO and CGE approach and investigate a wind range of scenarios investigating not only the impacts of increasing capacity, but also the impacts from changes in local content. Key results from our analysis can be found in Figures 6.1 and 6.2 below.

Figure 6.1: Key outputs from the macro-economic modelling – GVA (NPV).



Source: Author's calculations

Figure 6.2: Key outputs from the macro-economic modelling – Employment (NPV).



Source: Author's calculations

We modelled three different scenarios in this thesis: a single wind farm; planned Scottish capacity; and planned capacity with growth to 2030 using both an IO and CGE framework. As demonstrated by Figures 6.1 and 6.2 increasing the capacity of offshore will have a positive impact on the Scottish economy with an increase in GVA and the creation of jobs. The scale of these impacts vary depending on the scenario and model used, with the reasons for this explored in Chapters 4 and 5.

In the development of the IO and CGE models, this thesis also examines the electricity sector within the SNA framework. Also, we take a wider analysis of the impacts of Scottish offshore wind by using an electricity systems model to investigate impacts on the environment and security of supply. This section provides a summary of each chapter along with a summary of their contributions to the literature.

Chapter 1 is an introduction to this thesis to give the reader an insight to the Scottish electricity system. Scottish energy policy is introduced and it is noted that there has been a clear move to 'greener' energy policies over recent years. As well as energy policy, this introduction details the changes in the Scottish electricity system with a focus on wind energy.

In Chapter 2 we develop an Electricity Satellite Account (ElSA) for Scotland for 2012. Satellite accounts are commonly developed for sectors which are not well represented within the SNA framework but where there is a desire to have more detailed information. In the Scottish national accounts data, for example, electricity is a single sector incorporating all activities (generation, distribution, transmission and sales). The primary ElSA focus is on the interaction between electricity generation and the economy, each generator has different principle of operation and as such their interaction with the economy will differ – which the standard SNA framework is unable to capture.

The development of the Scottish ElSA is the first (to our knowledge) attempt at apply a satellite account to the electricity sector. Teliet (1984) is credited at identifying the possibility of such an account. As this is the first known attempt we establish a methodology for creating ELSAs by borrowing from Tourism Satellite Accounts (TSAs). TSAs are one of the most common types of TSAs and as such have a well-defined framework. We use and adapt the principles of TSAs to create the 2012 Scottish ElSA.

The 2012 Scottish ElSA contains 7 tables providing the reader with a comprehensive record of the electricity generation sector in Scotland. Tables 1-4 of the Scottish electricity focus on the generation of electricity which report on the value of electrical generation and consumption in 2012. Tables 5 and 6 link the satellite account with the SNA framework and Table 7 harbours employment data. Apart from the 7 core cables with the creation of the ElSA there is much more information regarding the relationship between electricity and the economy which can be determined – such as the variation in electricity price by technology.

Data from the Scottish ElSA is then used in Chapter 3 in the disaggregation of the electricity sector within the Scottish 2012 IxI table. The disaggregation of the electricity sector within IO accounts is not in itself new, there are several papers in the literature where this is done (Gay and Proops; Cruz, 2012). A primary reason for undertaking this disaggregation (as the focus of this PhD is on the electricity) is to overcome aggregation bias within the electricity sector. As identified in Chapter 2 each of the generators serves a different purpose and interacts with the economy in a distinct fashion. The disaggregation allows for these interactions to be identified and results in a more realistic model.

The contributions of Chapter 3 are that in our disaggregation we take a hybrid approach which accounts for the variation in the electricity price by generators. In the past disaggregation of the electricity sector has been applied using either a top down (Gay and Props, 1993) or survey approach (Allan et al, 2007). In our approach we use a combination of top down data and the assumptions from Gay and Props (1993) for some inputs and bottom-up (ElSA) data for more significant inputs (such as O&M).

Following on from Chapter 3, in Chapter 4 the electricity disaggregated IO table is used to calibrate an IO model which we use to determine the macroeconomic impacts from increasing offshore wind in Scotland. Detailed in the literature review of this chapter IO models have been extensively used in the economic assessments of renewable technologies thus this methodology was determined appropriate to use for this purpose.

In Chapter 4 the IO model is demand-driven and as such different ‘shocks’ were explored. Overall there were three different scenarios modelled (single medium sized offshore wind farm similar to a current in development wind farm, planned capacity and future) with varying simulations in each scenario. For these scenarios estimates were made (using a range of sources) on capacity, cost breakdown of turbine, local content etc.

Currently in the literature there are two reports which investigate the economic impacts of Scottish offshore wind using an IO modelling approach (Beatrice Offshore Wind farm Ltd, 2017, FAI). Both of these reports focus solely on a single wind farm with site specific data. The contribution of Chapter 4 of this thesis is that we investigate the cumulative impacts of all wind farms which are currently underway or being developed as well as difference in changes of local content. This chapter is key for policy as it allows policy makers to determine the economic impacts of increasing offshore wind developments.

CGE modelling is seen, by relaxing the assumptions, as the progression of IO models, with Chapter 5 using a CGE to again model use the economic impacts of Scottish offshore wind. IO models are a special case CGE with several assumption made most notably; the passive supply side; fixed prices and the use of Leontief production functions.

In Chapter 5 we use a version of the AMOS family of CGE models with disaggregated electricity sector using the Scottish ElSA from Chapter 3. This model allows for the IO assumptions to be relaxed and the examination of a higher level of variables than IO allows. For this thesis the electricity disaggregated AMOS was updated to 2012. A key input of a CGE is the SAM database and we develop a 2012 Scottish SAM using the disaggregated IO table and a developed income expenditure accounts.

The contribution of Chapter 5 is that this is the first (to our knowledge) assessment of the economic impacts of Scottish offshore wind using a CGE model. Unlike the IO model, where there is only impacts during shocks, CGE model capture impacts once the shocks have stopped - legacy effects. Again this CGE modelling is valuable to policy makers as they can determine a higher level of economic impacts along with the time paths.

6.2 Future work

As detailed above this PhD makes several contributions to the literature, however there are some areas of potential future work which is the focus of this section.

In Chapter 2 we – to our knowledge – develop the first electricity satellite account for Scotland in 2012, which allows for a better representation of the electricity sector within the SNA framework. With the Scottish ElSA we identify the consumption of electricity (by technology) by 12 sectors. A sensible extension of this work would to increase the number of consumption sectors and match with the IO tables. The data to increase the number of sectors was not available for this thesis, but with smart meters becoming ever more common, and reporting on the electricity maturing this may be possible for future ElSAs.

Also in Chapter 2 we develop the ElSA methodology and then to apply for Scotland. Future work for the ElSA would be to determine the methodologies suitability by applying for another region/country. An obvious extension to the work of this Chapter is to redo the Scottish ElSA using the most up to date data. For this thesis the data available was for 2012, however since then the Scottish electricity network has seen significant change – with coal generation now completely phased out. The Scottish IO tables are now available for 2015 making a 2015 Scottish ElSA possible, which we could compare with the 2012 ElSA and would expect large differences – especially Table 1 and 3.

Instead of only focusing on the electricity sector, an extension of the ElSA would be to incorporate other elements of the energy system (such as gas which is also only represented as a single sector within the SNA framework).

Noted n Figure 2, there are large seasonal variations in the Scottish electricity network, with the network replying much more on imports in the summer due to a reduction in wind generation. An extension of this work is that we could develop separate ElSAs for each season to better catch these variations. These seasonal ElSAs would also have the potential to be used in dynamic modelling of regional impacts of changes in the economy, whereby seasonal IO tables are used.

Chapter 3 of the thesis was focused on the disaggregation of the electricity sector within IO accounting for the variation in electricity price. We use this table in the analysis of increasing Scottish offshore wind capacity, focusing on the capital and O&M costs. An extension of this work is to use the new disaggregated table for investigation of economic changes focused on the electricity sectoral, one example being carbon tax.

In Chapters 4 and 5 we use both IO and CGE modelling methodologies to measure the potential economic impacts resulting from an increase in Scottish offshore wind capacity. An extension (future work) for both of these chapters would be to including more economic sectors, which would also require the development of an extended offshore wind bridge matrix.

In the modelling of the offshore wind we have solely focused on the impacts of an increase in expenditure (i.e demand shocks). Future work for Scottish offshore wind using a CGE framework would be to investigate the impacts of supply side changes. With an increase in offshore wind capacity there is likely to be an increase in industry learning with processes becoming more streamlined. A plan for the future is we could investigate the impact learning has on the labour and capital productivity of offshore wind and how this impacts the economy overall. Also, an extension of the CGE modelling would be to investigate the impacts an increase in Scottish offshore wind capacity has on employment in different skill levels within the economy.

Finally as identified in the introduction in this thesis economic development is only one of the four key pillars of the energy quadrilemma. An extension of the work in this thesis is to take a whole systems approach and look and not only the economic impacts but other components of the energy quadrilemma. The data from the ElSA could feed into an energy systems model whereby the impacts of increasing Scottish offshore wind capacity on energy security and emissions are investigated.

References

Algarin, J. V., Hawkins, T. R., Marriott, J., Matthews, H. S., & Khanna, V. (2014). Disaggregating the Power Generation Sector for Input-Output Life Cycle Assessment. *Journal of Industrial Ecology*, *Online Vol*(1).

Allan, G., McGregor, P. G., Swales, J. K., & Turner, K. (2007). Impact of alternative electricity generation technologies on the Scottish economy: an illustrative input—output analysis. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *221*(2), 243–254.

Allan, G. (2013). The Regional Economic Impacts of Biofuels: A Review of Multisectoral Modelling Techniques and Evaluation of Applications. *Regional Studies*, (November 2014), 1–29.

Allan, G. J., Lecca, P., McGregor, P. G., & Swales, J. K. (2014). The economic impacts of marine energy developments: A case study from Scotland. *Marine Policy*, *43*, 122–131.

Allan, G., Lecca, P., McGregor, P., & Swales, K. (2014b). The economic and environmental impact of a carbon tax for Scotland: A computable general equilibrium analysis. *Ecological Economics* , *100*, 40–50.

Ara, K. (2011). The Aggregation Problem in Input-Output. *Econmetrica*, *27*(2), 257–262.

Arcus Renewable Energy Consulting ltd. (2012). Beatrice Offshore Windfarm Non Technical Summary. *EIA Report*, (1), 1–47. Retrieved from http://www.gov.scot/Topics/marine/Licensing/marine/scoping/Beatrice

Armington, P. (1969). A theory of demand for products distinguished by place of production. *IMF Economic Review*, *16*(1), 159–178.

Arrow, K. J., & Debreu, G. (1954). Existence of an equilibrium for a competitive economy. *Econometrica*, *22*(3), 265–290.

Babatunde, K. A., Begum, R. A., & Said, F. F. (2017). Application of computable general equilibrium (CGE) to climate change mitigation policy: A systematic review. *Renewable and Sustainable Energy Reviews*, *78*(August 2016), 61–71.

Beatrice Offshore Windfarm LTd. (2017). Beatrice Offshore Windfarm Limited project - Socio - economic impact, (July).

BEIS. (2012). *Electricity Generation Costs*. https://doi.org/267393///1/1 25 May 2010

BEIS. (2013). *DECC Fossil Fuel Price Projections*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/212521/130718_decc-fossil-fuel-price-projections.pdf

BEIS. (2014). *Energy Consumption in the UK (2014) Chapter 5: Service sector energy consumption in the UK between 1970 and 2013*. Retrieved from https://www.gov.uk/government/statistics/electricity-section-5-energy-trends

BEIS. (2016a). *Electricity Generation Costs*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/566567/BEIS_Electricity_Generation_Cost_Report.pdf

BEIS. (2016). *Electricity generation and supply figures for Scotland , Wales , Northern Ireland and England , 2012 to 2015*. Retrieved from https://www.gov.uk/government/statistics/energy-trends-december-2016-special-feature-article-electricity-generation-and-supply-figures-for-scotland-wales-northern-ireland-and-england-2

BEIS. (2017a). *Electricity generation and supply figures for Scotland , Wales , Northern Ireland and England , 2013 to 2017*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/669719/Regional_Electricity_Generation_and_Supply.pdf

BEIS. (2017b). *Imports, Exports and Transfers of electricity*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/357534/Imports__exports_and_transfers_of_electricity.pdf

Bere, J., Jones, C., & Jones, S. (2015). *The economic and social impacts of small and community Hydro in Wales*. Retrieved from http://regenwales.org/upload/pdf/071015091201Impact of Small and Community Hydro in Wales.pdf

Blanco, M. I., & Rodrigues, G. (2009). Direct employment in the wind energy sector: An EU study. *Energy Policy*, *37*(8), 2847–2857. https://doi.org/10.1016/j.enpol.2009.02.049

Burfisher, M. (2011). *Introduction to General Equilbirium Models.pdf*. Cambridge University Press.

Burton, T., Sharpe, D., Jenkins, N., & Bossayanyi, E. (2011). *The Wind Energy Handbook* (Second). John Wiley & Sons, Ltd.

BVG Associates. (2010). *Value breakdown for the offshore wind sector*. *Renewables Advisory Board*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48171/2806-value-breakdown-offshore-wind-sector.pdf

BVG Associates. (2012). *UK content analysis of Robin Rigg Offshore Wind Farm operations and maintenance*. Retrieved from https://www.eonenergy.com/~/media/PDFs/Generation/wind/offshore/Eon_Robin_Rigg_OM_report.pdf

BVG Associates. (2014). *UK offshore wind supply chain : capabilities and opportunities*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/277798/bis-14-578-offshore-wind-supply-chain-capabilities-and-opportunities.pdf

BVG Associates. (2013). *Offshore Wind : A 2013 supply chain health check*. Retrieved from http://www.bvgassociates.co.uk/Portals/0/publications/BVGA TCE Offshore Wind SC Health Check 1311.pdf

BVG Associates. (2015). *Methodology for measuring the UK content of UK offshore wind farms*. Retrieved from http://www.renewableuk.com/en/publications/index.cfm/uk-content-methodology

Cansino, J. M., Cardenete, M. A., González-Limón, J. M., & Román, R. (2013). Economic impacts of biofuels deployment in Andalusia. *Renewable and Sustainable Energy Reviews*, *27*, 274–282.

Carbon Trust. (2015). *Floating Offshore Wind : Market and Technology Review*. Retrieved from http://www.carbontrust.com/media/670664/floating-offshore-wind-market-technology-review.pdf

Carroll, J., Mcdonald, A., Dinwoodie, I., Mcmillan, D., Revie, M., & Lazakis, I. (2017). A Comparison of the Availability and Operation & Maintenance Costs of Offshore Wind Turbines with Different Drive Train Configurations. *Wind Energy*, *20*(2), 361–378.

Carson, C., Grimm, B., & Moyland, C. (1994). A Satellite Account for Research and Development. *Survey of Current Business*, 37–71.

Centre for Economics and Business Research. (2012). The macroeconomic benefits of investment in offshore wind, (June), 1–44. Retrieved from http://mainstreamrp.com/content/reports/benefits-of-offshore-wind.pdf

Clarke, J. A., Kelly, N. J., & Tang, D. (2007). A Review of ESP-r's Flexible Solution Approach and its Application to Prospective Technical Domain Developments. *Advances in Building Energy Research*, *1*(1), 227–247. https://doi.org/10.1080/17512549.2007.9687277

Connolly, K., Allan, G. J., & McIntyre, S. G. (2016). The evolution of green jobs in Scotland: A hybrid approach. *Energy Policy*, *88*, 355–360. https://doi.org/10.1016/j.enpol.2015.10.044

Coulon, M., & Howison, S. (2009). Stochastic behaviour of the electricity bid stack: From fundamental drivers to power prices. *Journal of Energy Markets*, *2*(1), 29–69. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1418573

Cruz, L. M. G. (2002). Energy-Environment-Economy Interactions: An Input-Output Approach Applied to the Portuguese Case. In *7th Biennial Conference of the International Society for Ecological Economics* (p. 25). https://doi.org/10.1016/S0921-8009(01)00230-0

Crown estate Scotland. (2018). *Business Plan 2018-2019*. https://doi.org/10.1016/B978-0-323-43040-1.00001-4

Dalgic, Y., Lazakis, I., Dinwoodie, I., McMillan, D., & Revie, M. (2015). Advanced logistics planning for offshore wind farm operation and maintenance activities. *Ocean Engineering*, *101*, 211–226.

del Río, P., & Gual, M. A. (2007). An integrated assessment of the feed-in tariff system in Spain. *Energy Policy*, *35*(2), 994–1012.

Dilaver, Z. (2012). *Structural Times Series Modelling of Energy Demand*. Retrieved from http://www.seec.surrey.ac.uk/PGProgs/PhDTheses/2012ZaferDilaverThesis.pdf

Dixon, P. B., & Rimmer, M. T. (2016). Johansen's legacy to CGE modelling: Originator and guiding light for 50 years. *Journal of Policy Modeling*, *38*(3), 421–435.

Depuru, S. S. S. R., Wang, L., & Devabhaktuni, V. (2011). Smart meters for power grid: Challenges, issues, advantages and status. *Renewable and Sustainable Energy Reviews*, *15*(6), 2736–2742.

Debreu, G. (1959). Theory of Value: An Axiomatic Analysis of Economic Equilibrium. *Southern Economic Journal*.

Dowell, J., Weiss, S., Hill, D., & Infield, D. (2014). A simple atmospheric boundary layer model applied to large eddy simulations of wind turbine wakes. *Wind Energy*, *17*(April 2013), 657–

Elexon. (2013a). *The Electricity Trading Arrangements*. *Guidance paper*. Retrieved from https://www.elexon.co.uk/wp-content/uploads/2013/11/beginners_guide_to_trading_arrangements_v4.0_cgi.pdf

Elexon. (2013). *Imbalance Pricing Guidance*. Retrieved from https://www.elexon.co.uk/wp-content/uploads/2014/11/imbalance_pricing_guidance_v8.0.pdf

Elizondo, A., & Boyd, R. (2017). Economic impact of ethanol promotion in Mexico: A general equilibrium analysis. *Energy Policy*, *101*(September 2016), 293–301.

Emonts-Holley, T., Ross, A., & Swales, K. (2014). A Social Accounting Matrix for Scotland. *Fraser of Allander Institute Economic Commentary*, *38*(1), =. Retrieved from http://pdf.usaid.gov/pdf_docs/PNABI277.pdf

Emonts-Holley, T., Ross, A., & Swales, K. (2015). Type II erros in multipiers. *Discussion Papers in Economics*, *15–04*, 1–40.

Emonts-holley, T. (2016). Fiscal Devolution in Scotland: A Multi-Sectoral Analysis. *PhD Thesis, University of Strathclyde*, 1–436.

European Commision. (2009). *European Commission - The 2020 climate and energy package*. Retrieved from http://ec.europa.eu/clima/policies/package/

Eurostat. (1993). *System of national accounts, 1993* (Vol. 22). Retrieved from https://unstats.un.org/unsd/nationalaccount/docs/1993sna.pdf

Eurostat. (2008a). *2008 Tourism Satellite Account : Recommended Methodological Framework (TSA : RMF 2008)*. *Statistical Commission* (Vol. 39). Retrieved from http://unstats.un.org/unsd/statcom/doc08/BG-TSA.pdf

Eurostat. (2008). *Eurostat Manual of Supply, Use and Input-Output Tables*. *Methodologies and working papers*, *Economy and finance*. https://doi.org/http://ec.europa.eu/eurostat

Eurostat. (2016). *Tourism Satellite Accounts in Europe*. Retrieved from http://ec.europa.eu/eurostat/web/products-statistical-reports/-/KS-FT-17-002

FAI. (2017a). *The potential macroeconomic impacts of floating offshore wind : a methodological guide*.

FAI. (2017b). *Economic impact of the proposed Neart Na Gaoithe offshore windfarm*. Retrieved from https://www.sbs.strath.ac.uk/economics/fraser/201708/NNG-Impact-Report.pdf.

Fanning, T., Jones, C., & Munday, M. (2014). The regional employment returns from wave and tidal energy : A Welsh analysis. *Energy*, *76*, 958–966.

Farinaccio, L., & Zmeureanu, R. (1999). Using a pattern recognition approach to disaggregate the total electricity consumption in a house into the major end-uses. *Energy and Buildings*, *30*(3), 245–259.

Frechtling, D. C. (1999). The toursim satellite account foundations, progress and issues. *Toruism Management*, *20*(1), 163–170.

Frechtling, D. C. (2010). The toruism satellite account: A Primer. *Annals of Tourism Research*, *37*(1), 136–153.

GL Garrad Hassan. (2013). *A guide to UK offshore wind operations and maintenance*. Retrieved from https://www.scottish-enterprise.com/knowledge-hub/articles/guide/offshore-wind-operations-and-maintenance-opportunities

Gay, P. W., & Proops, J. L. R. (1993). Carbondioxide production by the UK economy: An input-output assessment. *Applied Energy*, *44*(2), 113–130. https://doi.org/10.1016/0306-2619(93)90057-V

Gill, S., & Bell, K. (2017). Meeting Scotland's peak demand for electricity, (March), 1–7. Retrieved from http://www.climatexchange.org.uk/files/3914/9028/4833/CXC_security_of_electricity_supply_Short_report.pdf

Gilmartin, M. (2010). Evaluating the Economy-Wide Impact of Demand and Supply Disturbances in the UK: A Computable General Equilibrium Analysis of Current Regional and National Policy Concerns. *PhD Thesis, University of Strathclyde*, 1–363.

Gilmartin, M., & Allan, G. (2014). Regional Employment Impacts of Marine Energy in the Scottish Economy: A General Equilibrium Approach. *Regional Studies*, (November), 1–19.

Garton Grimwood, G., & Ares, E. (2016). Energy : The Renewables Obligation. *House of Commons Briefing Paper*, (5870), 1–10.

Graziano, M., Lecca, P., & Musso, M. (2017). Historic paths and future expectations: The macroeconomic impacts of the offshore wind technologies in the UK. *Energy Policy*, *108*(November 2016), 715–730. https://doi.org/10.1016/j.enpol.2017.06.042

Greenway, D., Leybourne, S. J., Reed, G, V., & Whalley, J. (1993). *Applied General Equilibrium Modelling: Applications, Limitations and Future Development*

Goldberg, M., & Milligan, M. (2004). Job and economic development impact (JEDI) model: A user-friendly tool to calculate economic impacts from wind projects. *2004 Global Windpower*, (March), 1–11.

Harrigan, F., McGregor, P. G., Dourmashkin, N., Perman, R., Swales, K., & Yin, Y. P. (1991). AMOS. A macro-micro model of Scotland. *Economic Modelling*, *8*(4), 424–479.

Harrison, A. (2006). Satellite Accounts. In *Fourth meeting of the Advisory Expert Group on National Accounts* (pp. 1–3).

Hayashi, F. (1982). Tobin's Marginal q and Average q : A Neoclassical Interpretation. *Econometrica*, *50*(1), 213–224.

Heerschap, N., de Boer, B., Hoekstra, R., van Loon, A., & Tromp, L. (2005). A Tourism Satellite Account for the Netherlands: Approach and results. *Tourism Economics*, *11*(3), 393–409. https://doi.org/10.5367/000000005774353024

Hesmondhalgh, S. (2012). *GB Electricity Demand – Initial Brattle Electricity Demand-Side Model*. *GB Electricity Demand Project*. Retrieved from http://docplayer.net/5149427-Gb-electricity-demand-2010-and-2025-initial-brattle-electricity-demand-side-model-scope-for-demand-reduction-and-flexible-response.html

HM Treasury. (2018). *The Green Book*. *HM Treasury: London*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf

Horrowitz, K. J., & Planting, M. A. (2009). *Concepts and Methods of the U . S . Input-Output Accounts*.

Innovas Solutions. (2011). *Scotland Low Carbon and Environmental Goods and Services Sector Study*. Retrieved from http://www.gov.scot/Resource/Doc/344829/0114756.pdf

Jenniches, S.. (2018). Tourism satellite accounts for regions? a review of development issues and an alternative. *Renewable and Sustainable Energy Reviews, 93(May), 35–51.*

Jones, C., & Munday, M. (2010). Assessing the regional economic impacts of renewable energy sources A literature review. *Economic Systems Research*, *22*(4), 341–358.

Jones, C., Munday, M., Bryan, J., Roberts, A., McNicoll, I., & McLellan, D. (2005). *UK Tourism Satellite Account - First Steps Project*. Retrieved from http://old.culture.gov.uk/images/research/tsafirststepprojectreportpt1.pdf

Jones, C., Bryan, J., & Munday, M. (2010). *The Input–Output Tables for Wales 2007*. Retrieved from https://www.cardiff.ac.uk/__data/assets/pdf_file/0010/698869/input-output-tables-2007-final-30-6.pdf.

Johansen. (1960). *A multi-sectoral study of economic growth.*

Jorgenson, Dale, W. (1963). Capital Theory and Investment Behavior. *American Economic Association*, *53*(2), 247–259.

Kern, F., Smith, A., Shaw, C., Raven, R., & Verhees, B. (2014). From laggard to leader: Explaining offshore wind developments in the UK. *Energy Policy*, *69*, 635–646.

Kymn, K. O. (1990). Aggregation in Input-Output Models: A Comprehensive Review, 1946–71. *Economic Systems Research*, *2*(1), 65–93.

Layard, R., Nickell, S., & Jackman, R. (1991). *Unemployment macroeconomic performance and the labour market*. JSTOR.

Lecca, P., Swales, K., & Turner, K. (2011). An investigation of issues relating to where energy should enter the production function. *Economic Modelling*, *28*(6), 2832–2841.

Lecca, P., McGregor, P. G., & Swales, J. K. (2013). Forward-looking and myopic regional Computable General Equilibrium models: How significant is the distinction? *Economic Modelling*, *31*(1), 160–176.

Lecca, P., McGregor, P. G., Swales, K. J., & Tamba, M. (2017). Corrigendum to "The Importance of Learning for Achieving the UK's Targets for Offshore Wind" [Ecol. Econ. 135 (2017) 259–268] (S0921800915302822) (10.1016/j.ecolecon.2017.01.021). *Ecological Economics*, *137*, 231.

Leontief, W. W. (1936). Quantitative Input and Output Relations in the Economic Systems of the United States Author(s): Wassily W. Leontief. *The Review of Economics and Statistics*, *18*(3), 105–125.

Lewis, J. I., & Wiser, R. H. (2007). Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. *Energy Policy*, *35*(3), 1844–1857.

Liu, C. H., Lenzen, M., & Murray, J. (2012). A disaggregated emissions inventory for Taiwan with uses in hybrid input-output life cycle analysis (IO-LCA). *Natural Resources Forum*, *36*(2), 123–141.

Madlener, R., & Koller, M. (2007). Economic and CO2mitigation impacts of promoting biomass heating systems: An input-output study for Vorarlberg, Austria. *Energy Policy*, *35*(12), 6021–6035.

Mainstream Renewable Power. (2012). Non - Technical Summary Neart na Gaoithe Offshore Wind Farm Environmental Statement. *EIA Report*, *1*, 1–13. Retrieved from http://mainstream-downloads.opendebate.co.uk/downloads/Non-Technical-Summary.pdf

Markaki, M., Belegri-Roboli, A., Michaelides, P., Mirasgedis, S., & Lalas, D. P. (2013). The impact of clean energy investments on the Greek economy: An input-output analysis (2010-2020). *Energy Policy*, *57*, 263–275.

Marriott, J. (2007). *An Electricity-focused Economic Input-ou tput Model: Life-cycle Assessment and Policy Implications of Future Electricity Generation Scenarios*. *PhD Thesis, Carnegie Mellion University*.

McIntrye, S. (2012). *Regional economic and environmental analysis*. *PhD Thesis, University of Strathclyde*.

Mcmanus, B. Y. M. (1956). On Hatanaka’ s Note on Consolidation. *Econmetrica*, *24*(4), 482–487.

McKitrick, R. R. (1998). The econometric critique of computable general equilibrium modeling: the role of functional forms. *Economic Modelling*, *15*(4), 543–573. https://doi.org/10.1016/S0264-9993(98)00028-5

Meis, S., Joyal, S., Lapierre, J., & Joisce, J. (2004). The Canadian Tourism Satellite Account a new tool for measuring tourism’s economic contribution. *Estudios Turísticos*, *162*, 408–420.

Miller, R. E., & Blair, P. D. (2009). *Input-Output Analysis. Foundations and Extensions.* (Second). Cambridge University Press.

Mirasgedis, S., Tourkolias, C., Pavlakis, E., & Diakoulaki, D. (2014). A methodological framework for assessing the employment effects associated with energy efficiency interventions in buildings. *Energy and Buildings*, *82*, 275–286.

Mone, C., Hand, M., Bolinger, M., Rand, J., Heimiller, D., & Ho, J. (2017). 2015 Cost of Wind Energy Review. *Nrel*, (May).

Moray Offshore Renewables ltd. (2013). Developing Wind Energy In The Outer Moray Environmental Report. *EIA Report*, *1*, 1–60. Retrieved from http://morayoffshorerenewables.com/Document-Library.aspx?path=environmental+statement&fileid=58

Morimoto, Y. (1970). On Aggregation Problems in Input-Output Analysis. *The Review of Economic Studies*, *37*(1), 119–126. https://doi.org/10.2307/2296502

Mu, Y., Cai, W., Evans, S., Wang, C., & Roland-Holst, D. (2018). Employment impacts of renewable energy policies in China: A decomposition analysis based on a CGE modeling framework. *Applied Energy*, *210*(October 2017), 256–267.

National audit office. (2014). *Electricity Balancing Services*. Retrieved from https://www.nao.org.uk/wp-content/uploads/2014/05/Electricity-Balancing-Services.pdf

Navani, J. P., Sharma, N. K., & Sapra, S. (2012). Technical and Non-Technical Losses in Power System and Its Economic Consequence in Indian Economy. *International Journal of Electronics and Computer Science Engineering*, *1*(2), 757–761.

Olabi, A. G. (2016). Energy quadrilemma and the future of renewable energy. *Applied Energy*, *108*, 1–6.

OECD. (2008). *The System of National Accounts 2008. United Nations, New York*. https://doi.org/10.1057/ukna.2008.3

Offshore Wind Industry Group. (2009). *Scotland ' s Offshore Wind Route Map Developing Scotland ' s Offshore Wind Industry to 2020 and Beyond*. Retrieved from http://www.gov.scot/Resource/0041/00413483.pdf

Office of National Statistics. (2008). *Proposals for Satellite Accounts*. Retrieved from http://www.ons.gov.uk/ons/guide-method/ukcemga/publications-home/publications/archive/proposals-for-satellite-accounts.pdf

Office of National Statistics. (2016). *The UK Tourism Satellite Account (UK-TSA):* Retrieved from https://www.ons.gov.uk/economy/nationalaccounts/satelliteaccounts/bulletins/uktourismsatelliteaccountuktsa/2013

Ofgem. (2012). *Demand side response in the non-domestic sector*. Retrieved from https://www.ofgem.gov.uk/publications-and-updates/demand-side-response-non-domestic-sector

ORE Catapult. (2014). *Impact Study into the Development of the UK Offshore Renewable Energy Industry to 2020*. *Project Report*. Retrieved from https://ore.catapult.org.uk/documents/10619/101377/pdf/808ecf6e-4392-40e3-9d89-bf8458a6a2ca

Orecca. (2018). *UK Annyal offshorwe wind speeds*. Retrieved from http://map.rse-web.it/orecca/map.phtml

Reategui, S., & Tegen, S. (2008). Economic Development Impacts of Colorado ' s First 1000 Megawatts of Wind Energy. In *Windpower 2008* (pp. 1–25). Retrieved from http://www.nrel.gov/docs/fy08osti/43505.pdf

Reichmuth, H. (2008). A Method for Deriving an Empirical Hourly Base Load Shape from Utility Hourly Total Load Records. In *ACEE summer study on energy efficency in buildings* (pp. 235–247). Retrieved from http://aceee.org/files/proceedings/2008/data/papers/5_256.pdf

Renewable UK. (2017a). *Offshore Wind Projects Offshore Wind Project Timelines*. https://doi.org/https://www.renewableuk.com/news/news.asp?id=294516

Renewable UK. (2017b). *Offshore Wind Industry Investment in the UK 2017*. Retrieved from https://www.renewableuk.com/news/362764/Offshore-Wind-Industry-Investment-in-the-UK.htm

Repsol; EDP Renewables. (2014). Inch Cape Wind Farm Onshore Non Technical Summary. *EIA Report*, (1), 1–36. Retrieved from http://www.inchcapewind.com/files/OnshoreES/Non_Technical_Summary.pdf

Partridge, M. D., & Rickman, D. S. (1998). Regional Computable General Equilibrium Modelling: A Survey and Critical Appraisal. *International Regional Science Review*, *21*(3), 205–248.

Ross, A. (2017). *Household and skill disaggregation in multi-sectoral models of the Scottish Economy*. *PhD Thesis, University of Strathclyde*.

Royles, E., & McEwen, N. (2015). Empowered for action? Capacities and constraints in sub-state government climate action in Scotland and Wales. *Environmental Politics*, *24*(6), 1034–1054.

Llera Sastresa, E., Usón, A. A., Bribián, I. Z., & Scarpellini, S. (2010). Local impact of renewables on employment: Assessment methodology and case study. *Renewable and Sustainable Energy Reviews*, 14(2), 679–690.

Scarf, H. (1967). The Approximation of Fixed Points of a Continuous. *Journal of Applied Mathematics*, *15*(5), 1328–1343.

Scottish Government. (2009). *Climate Change (Scotland) Act 2009* (Vol. 2009). Retrieved from http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/climatechangeact

Scottish Government. (2011a). *2020 Roadmap for renewable energy in Scotland*. Retrieved from http://www.scotland.gov.uk/resource/doc/917/0118802.pdf

Scottish Government. (2011). *Input-Output Methodology Guide*. Retrieved from http://www.gov.scot/Topics/Statistics/Browse/Economy/Input-Output/MultiplierMethodology

Scottish Government. (2014). *Energy in Scotland 2014*. Retrieved from http://www.gov.scot/Resource/0044/00444530.pdf

Scottish Government. (2016). The Climate Change (Annual Targets) (Scotland) Order 2016, *5*(328), 2030–2033. Retrieved from http://www.legislation.gov.uk/ssi/2016/328/pdfs/ssi_20160328_en.pdf

Scottish Government. (2017a). *Energy in Scotland 2017*. Retrieved from http://www.gov.scot/Topics/Statistics/Browse/Business/Energy/EIS/EIS2017

Scottish Government. (2017b). *Scottish Energy Strategy*. Retrieved from http://www.gov.scot/Resource/0052/00529523.pdf

Scottish Government. (2018a). Energy Statistics for Scotland March : CM8, 7–9. Retrieved from http://www.gov.scot/Resource/0053/00533679.pdf

Scottish Government. (2018c). *2014 Scottish Input Output tables*. Retrieved from http://www.gov.scot/Topics/Statistics/Browse/Economy/Input-Output/Downloads

Scottish Power. (2013). *Longannet Power Station EMAS statemenet 2012*. Retrieved from https://www.scottishpower.com/userfiles/file/EMASfinallo.pdf

Scottish Renewables. (2012). *Delivering the ambition: Employment in renewable energy in Scotland*. *Report*. Retrieved from http://www.scottishrenewables.com/media/uploads/publications/final_sr_jobs_report_21032012_-web.pdf

Scottish Renewables. (2014). *East Anglia one Supply Chain Plan*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/429411/EA1_SC_plan_600MW_DECC_Shortened_19.3.15.pdf

Seagreen Wind Energy. (2012). Firth of Forth Wind Farm Non-Technical Summary. *EIA Report*, (1), 1–27. Retrieved from http://www.seagreenwindenergy.com/assets/seagreen-phase-1-offshore-nts.pdf

Shoven, J. B., & Whalley, J. (n.d.). Shoven, J. B., & Whalley, J. (1992). Applying general equilibrium.pdf.

Skantze, P., Gubina, A., & Ilic, M. (2000). Bid-based stochastic model for electricity prices: the impact of fundamental drivers on market dynamics. *Energy Laboratory Publications MIT*, *4*(November), 2–61.

Slattery, M. C., Lantz, E., & Johnson, B. L. (2011). State and local economic impacts from wind energy projects: Texas case study. *Energy Policy*, *39*(12), 7930–7940.

Statisitc New Zeland. (2009). *Tourism Satellite Account 2009*. Retrieved from http://archive.stats.govt.nz/browse_for_stats/industry_sectors/Tourism/tourism-satellite-account-info-releases.aspx

Stone, R. (1984). The Accounts of Society (Nobel lecture). *Economic Sciences*, 116–138.

Smeral, E. (2006). Tourism Satellite Accounts: A Critical Assessment. *Journal of Travel Research*, *45*(August), 92–98. https://doi.org/10.1177/0047287506288887

Smith, S. L. ., & Wilton, D. (1997). TSAs and the WTTC/WEFA Methodology: Different Satellites or Different Planets? *Tourism Economics*, *3*(3), 249–263.

Snodin, H., Gow, G., & Garrad, A. (2001). *Scotland's renewable resource*. *Analysis* (Vol. I). Retrieved from http://archive.scottish.parliament.uk/business/committees/enterprise/inquiries/rei/ec04-reis-scotenvlinkfollowup2.pdf

Steeg, A. Van De. (2009). *Accounting for Tourism The Tourism Satellite Account (TSA) in Perspective*.

Tamba, M. (2014). Technological Change and Sustainable Energy Policies Modelling Exercises for Scotland and the UK. *PhD Thesis*, *University of Strathclyde*, 1–330.

Teillet, P. (1988). a Concept of Satellite Account in the Revised Sna. *Review of Income and Wealth*, *34*(4), 411–439.

Tegen, S., Keyser, D., Miles, J., Zammit, D., Loomis, D., Tegen, S., & Keyser, D. (2015). *Offshore Wind Jobs and Economic Development Impacts in the United States : Four*

Regional Scenarios Offshore Wind Jobs and Economic Development Impacts in the United States : Four Regional Scenarios. *NERL report*. Retrieved from http://www.nrel.gov/docs/fy15osti/61315.pdf

The Crown Estate. (2010). *A Guide to an Offshore Wind Farm*. Retrieved from http://www.thecrownestate.co.uk/guide_to_offshore_windfarm.pdf

Theil, H. (1957). Linear Aggregation in Input-Output Analsyis. *Econmetrica*, *25*(1), 111–122.

UK Government. (1989). *The Electricity Act 1989*. Retrieved from http://www.legislation.gov.uk/ukpga/1989/29/introduction

UK Government. (1998). *Scotland Act 1998*. Retrieved from http://www.legislation.gov.uk/ukpga/1998/46/part/I

UK Government. (2008). *Climate Change Act 2008*. Retrieved from http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf

UK Government. (2013). *Energy Act 2013*. *HM Government*. Retrieved from http://www.legislation.gov.uk/ukpga/2013/32/contents/enacted

UK Government. (2017). *Contracts for Difference Second Allocation Round Results*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/643560/CFD_allocation_round_2_outcome_FINAL.pdf

Walras, I. (1926). *Walras Elements of pure economics or the theory of social wealth (translated)*. George Allen and Unwin Ltd.

Welsh Economy Research Unit. (2013). RenewableUK Cymru Economic Opportunities for Wales from Future Onshore Wind Development, 1–66. Retrieved from http://www.renewableuk-cymru.com/wp-content/uploads/2013/10/EconomicOpportunitiesOnshoreWindWales.pdf

Wiedmann, T. O., Suh, S., Feng, K., Lenzen, M., Acquaye, A., Scott, K., & Barrett, J. R. (2011). Application of hybrid life cycle approaches to emerging energy technologies - The case of wind power in the UK. *Environmental Science and Technology*, *45*(13), 5900–5907.

Wind Europe. (2017). The European offshore wind industry - Key trends and statistics 2016. *Wind Europe*, (January), 33. Retrieved from Wind Europe. (2017). The European offshore wind industry - Key trends and statistics 2016

Winning, M. (2012). *An analysis of UK climate change policy institutions and instruments*. *PhD Thesis*, *University of Strathclyde*. Retrieved from http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.576307

Wolsky, A. M. (1984). Disaggregating input-output models. *The Review of Economics and Statistics*, *66*(2), 283–291. Retrieved from http://www.jstor.org/stable/1925829?seq=1#page_scan_tab_contents

World Energy Council. (2016). *World Energy Trilemma 2016 Defining Measures To Accelerate the Energy Transition*. *World Energy Council Report*. Retrieved from http://www.worldenergy.org/publications/2016/world-energy-trilemma-2016-defining-measures-to-accelerate-the-energy-transition/

Appendix 1A – Scottish offshore wind developments (Renewables UK, 2017)

Operation

Table 1A.1: Operational offshore wind farms In Scotland.

Development	Size (MW)	Completion date
Robin Rigg	174	2010
Hywind (Floating)	30	2017

Consented/Construction

Table 1A.2: Consented offshore wind farms In Scotland.

Development	Size (MW)	Completion date
Aberdeen Bay	100	2018
Beatrice	588	2019
Inch Cape	750	2021
Moray East (Phase 1)	504	2022
Neart Na Golthe	450	2022
Kincardine (Floating)	48	N/A

Development

Table 1A.3: Developmental offshore wind farms In Scotland.

Development	Size (MW)	Completion date
Firth of Forth – Phase 1	1050	N/A
Firth of Forth – Phase 2	1800	N/A
Firth of Forth – Phase 3	800	N/A
Moray East (Phase 1)	750	2025/6

Appendix 1B – Other UK offshore wind developments (Renewables UK, 2017)

Operation

Table 1B.1: Operational offshore wind farms in the RUK

Development	Size (MW)
Barrow	90
Burbo Bank	90
Burbo Bank extentsion	258
Greater Gabbard	504
Gunfleet 2ands 1	108
Gunfleet Sands 2	65
Gwynt y Mor	576
Humber Gateway	219
Kentish Flats 1	90
Kentish Flats Extension	50
North Hoyle	60
Lincs	270
London Array	630
Lynn & Inner Dowsing	194
Ryhl Flats	90
Ormonde	150
Scroby Sands	90
Shering Shoal	317
Teesside	62
Thanet	300
Walney 1 &2	367
Westermost Rough	210
West of Duddon Sands	389

Consented/Construction

Table 1B.2: Consented offshore wind farms in the RUK

Development	Size (MW)
Dogger Bank Creyke Beck A	<1200
Dogger Bank Creyke Beck B	<1200
Dogger Bank Teesside A	<1200
Dogger Bank Teesside A	<1200
Dudgeon	402
East Anglia 1	714
Galloper	336
Hornsea 1	1200
Hornsea 2	1200
Racebank	573
Rampion	400
Triton Knoll	900
Walney Extension	<660

Development

Table 1B.3: Developmental offshore wind farms in the RUK

Development	Size (MW)
East Anglia 1 North	600-800
East Anglia 2	600-800
East Anglia 3	1200
Dogger Bank Teesside A	<1200
Hornsea 3	2400
Hornsea 4	1000
Norfolk Boreas	N/A
Norfolk Vanguard	<1800
Thanet extension	<1800

Appendix 2A – Wind energy estimation model

The Elexon portal contains information on transmission connected/or large distribution (such as Clyde (350MW) - and Whitelee (539MW)) wind farms. We estimate that this data captures 24.3% of all onshore wind sites in Scotland but a larger (61.68%) in terms of generation due to them being the higher capacity wind farms. Offshore wind farms are not included in this model as the data for the Robin Rigg – the only offshore wind farm in Scotland – is available from Elexon[94].

To overcome the problem of not all wind capacity captured within Elexon, a model was developed to estimate the output of the smaller distributed wind farms, which (partly) uses information of the larger windfarms. The model operates under the assumption that wind farms in close proximity will experience similar wind speeds. In terms of determining wind speeds there are much more advanced models (Dowell et al, 2014) which require considerably more data than was available in the creation of the Scottish ElSA, but the model explained below was found to be adequate for our purpose.

Firstly each distributed connected wind farm had to be identified. This was achieved under the presumption that any windfarm not connected to the transmission system must be distributed connected[95]. The UK energy database (Renewables UK, 2017) contains information on every wind farm in the UK and using this and Elexon we identified 78 distributed connected windfarms in Scotland in 2012. The location of each wind farm was determined and the straight line distance between each and its closest wind farm connected to the transmission network was calculated.

[94] In the future it is likely that all offshore wind farms will be included in Elexon as they are large scale projects

[95] Autonomous generation is not taken into account in the development of ElSA – this is a small share of total electrical output and the electricity is not traded on the market

Most modern day wind turbines operate under the same principle, being that they are pitch regulated variable speed. The major difference is in the configuration of the drive-trains, which have no effect on the power curve. This fact of being similar in operation was used in the wind model to translate wind speeds and wind farm capacity to wind output. Figure 2A.1 shows a generic power curve for modern day onshore wind turbines.

Figure 2A.1: Power curve of generic pitch regulated variable speed wind turbine.

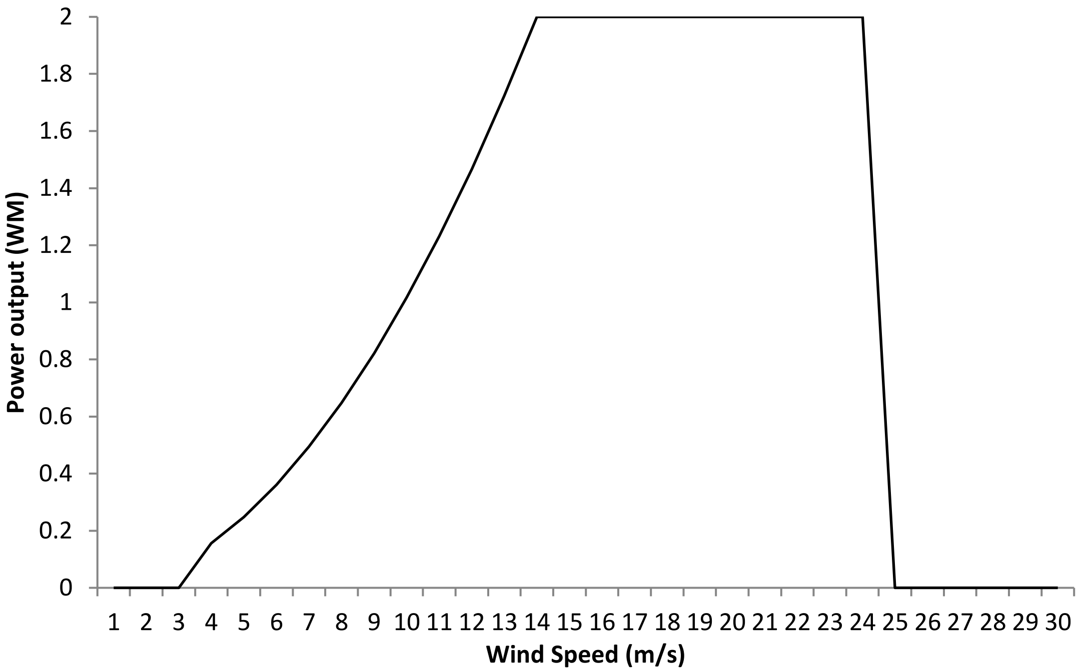


Figure 2A.1 shows how pitch regulated variable speed wind turbines work at different wind speeds. At speeds of under 3ms^{-1} there is insufficient wind for the blade to rotate, thus no power output. After this 3ms^{-1} fresh hold (the cut-in wind speed) the turbine will start to generate power output in a cubic ratio to the wind speed. As the power output is increasing the rotor speed is variable to maximise the coefficient of performance (efficiency) of the rotor. At 14ms^{-1} the turbine reaches rated power at which point the pitch system controls the aerodynamic properties of the turbine by moving the blades for a constant maximum output. If this pitching mechanism was not present the turbine would begin to stall and reduce power output. This pitching system continues up until 25ms^{-1} at which, for safety concerns, the turbine is switched off.

While the power curve seen above is an illustration of typical power output for a variable speed pitch regulated, a similar profile is followed for different turbines. The precise cut in, rated and cut out wind speeds and power will vary depending on the size and make of the turbine. Information about the power curve for most wind turbines in operation in Scotland today is available in the public domain (The wind power, 2016).

From the wind power database and our mapping, we can identify the location, distance to nearest transmission windfarm and power curve for every distribution-grid connected windfarm in Scotland. This information allows the estimation of output for each windfarm, at each half hourly time step, to be made. Firstly for every transmission connected windfarm, at each time-step the output of an 'average' wind turbine must be found using Equation A2.1[96].

$$Ouput\ of\ 1\ turbine\ (MWh)(t) = \frac{Overall\ wind\ farm\ output\ (MWh)(t)}{number\ of\ turbines} \qquad \text{(A2.1)}$$

This 'average' output information can be cross-referenced with the turbine power curve to estimate the half-hourly wind speed for that wind farm. These wind speeds are then use to calculate the power output at each of the distribution wind farm using Equation A2.2.

$$Half\ hour\ output\ (MW) = Mean\ wind\ speed(ms^{-1}) * Power\ curve\ output\ at\ wind\ speed\ (MW) \qquad \text{(A2.2)}$$

With these calculations we then have an estimation for the total wind generation in Scotland. Our estimation of total wind generation was 8,148 GWh which is very close to that published by BEIS (2013b) for total wind and wave (which there will be very little of) generation in 2012 in Scotland (8,205 GWh). This therefore completes the total outputs of all generation technologies in Scotland which is primary used in the development of Table 1 to 4 of the ElSA.

[96] This is the average speed seen by each of the turbines. In reality each turbine will experience a slightly wind speed, with the introduction of wakes etc, but this is not needed for our model as we are using overall farm output

Appendix 2B – Full ElSA tables for Scotland

Table 2B.1: 2012 Scottish ElSA Table 1/ Imported electricity by expenditure (£m)

Product	Domestic	Industrial	Office	Communication	Education	Government	Health	Hotel	Other	Retail	Sport	Warehouse	Total
Coal	3.14	2.43	0.23	0.12	0.24	0.16	0.10	0.27	0.12	0.77	0.13	0.28	7.99
Gas	2.64	2.12	0.20	0.10	0.21	0.14	0.09	0.23	0.10	0.65	0.11	0.24	6.83
Nuclear	1.54	1.17	0.11	0.06	0.12	0.08	0.05	0.13	0.06	0.38	0.06	0.14	3.90
Pumped generation	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.15
Hydro	0.08	0.07	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.00	0.01	0.21
Wind	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.01	0.16
Other	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.05
Total	7.54	5.90	0.56	0.29	0.59	0.39	0.25	0.64	0.29	1.86	0.31	0.68	19.30

Source: Author's calculation

Table 2B.2 2012: Scottish ElSA Table 2. Domestic use electricity by expenditure (£m)

Product	Domestic	Industrial	Office	Communication	Education	Government	Health	Hotel	Other	Retail	Sport	Warehouse	Pumped storage	Generators	Losses	Total
Coal	117.79	84.41	8.47	4.59	8.19	5.79	3.82	10.28	33.37	29.57	4.83	10.66	5.96	33.69	27.81	389.23
Gas	55.79	40.31	4.05	2.19	3.93	2.76	1.82	4.90	16.47	14.10	2.30	5.07	2.79	11.17	13.17	180.83
Nuclear	166.87	119.62	12.09	6.60	11.61	8.23	5.47	14.80	50.61	42.41	6.88	15.24	9.71	42.13	39.27	551.53
Pumped generation	47.95	34.54	3.42	1.84	3.35	2.35	1.54	4.10	14.45	11.88	1.96	4.31	1.96	5.34	11.17	150.15
Hydro	8.15	5.63	0.54	0.28	0.53	0.38	0.24	0.63	2.24	1.87	0.32	0.68	0.01	2.76	1.77	26.04
Wind	75.87	55.01	5.51	2.99	5.33	3.77	2.49	6.70	20.54	19.25	3.14	6.94	4.12	9.72	19.24	240.62
Other	20.19	14.49	1.43	0.77	1.40	0.99	0.64	1.72	6.20	4.98	0.82	1.81	0.87	3.66	4.72	64.70
Total	492.61	354.01	35.53	19.27	34.33	24.27	16.01	43.14	143.88	124.04	20.24	44.72	25.42	108.48	117.16	1603.11

Source: Author's calculation

Table 2B.3: 2012 Scottish ElSA Table 3. Exported electricity by expenditure (£m)

Product	England Exports	NI Exports	Total
Coal	107.98	23.40	131.39
Gas	54.72	11.58	66.30
Nuclear	148.16	35.38	183.54
Pumped generation	49.84	9.62	59.45
Hydro	5.71	1.53	7.24
Wind	105.19	15.26	120.45
Other	19.86	3.99	23.86
Total	491.47	100.76	592.23

Source: Author's calculation

Table 2B.4: 2012 Scottish ElSA Table 4. Domestic generated electricity by expenditure (£m)

Product	Domestic	Industrial	Office	Comm	Education	Government	Health	Hotel	Other	Retail	Sport	Warehouse	PS	Gen	Losses	E export	NI export	Total
Coal	117.8	84.4	8.5	4.6	8.2	5.8	3.8	10.3	33.4	29.6	4.8	10.7	6.0	33.7	27.8	108.0	23.4	520.6
Gas	55.8	40.3	4.1	2.2	3.9	2.8	1.8	4.9	16.5	14.1	2.3	5.1	2.8	11.2	13.2	54.7	11.6	247.1
Nuclear	166.9	119.6	12.1	6.6	11.6	8.2	5.5	14.8	50.6	42.4	6.9	15.2	9.7	42.1	39.3	148.2	35.4	735.1
Pumped generation	47.9	34.5	3.4	1.8	3.3	2.4	1.5	4.1	14.4	11.9	2.0	4.3	2.0	5.3	11.2	49.8	9.6	209.6
Hydro	8.2	5.6	0.5	0.3	0.5	0.4	0.2	0.6	2.2	1.9	0.3	0.7	0.0	2.8	1.8	5.7	1.5	33.3
Wind	75.9	55.0	5.5	3.0	5.3	3.8	2.5	6.7	20.5	19.2	3.1	6.9	4.1	9.7	19.2	105.2	15.3	361.1
Other	20.2	14.5	1.4	0.8	1.4	1.0	0.6	1.7	6.2	5.0	0.8	1.8	0.9	3.7	4.7	19.9	4.0	88.6
Total	492.6	354.0	35.5	19.3	34.3	24.3	16.0	43.1	143.9	124.0	20.2	44.7	25.4	108.5	117.2	491.5	100.8	2195.3

Source: Author’s calculation

Table 2B.5 2012 Scottish ElSA Table 5. Production account

Products	**Electricity generation production account (£m)**								
	Coal industry	Gas industry	Nuclear industry	Flow industry	Pumped	Wind industry	Other Industry	Other industries	Total output
Coal	19.8	-	-	5.6	6.0	7.1	1.2	204.0	243.6
Gas	-	4.8	-	2.6	2.8	3.2	0.5	97.9	111.9
Nuclear	-	-	23.8	7.1	9.7	9.8	1.4	293.6	345.4
Flow	-	-	-	2.2	2.0	2.8	0.4	83.7	91.0
Pumped generation	-	-	-	0.4	1.9	0.4	0.1	13.3	16.1
Wind	-	-	-	2.8	4.1	6.5	0.5	131.7	145.5
Other	-	-	-	0.6	0.9	0.7	2.3	35.3	39.8
Non-generation	-	-	-	-	-	-	-	64,667	64,667
GVA	92.4	96.8	405.8	2448.8		489.0	29.4	54,161	55,520

Source: Author's calculations

Table 2B.6: Scottish 2012 ElSA Table 6.

Products	**Supply of Scottish electricity (£m)**					
	Output	**Exports**	**Taxes less subsidies**	**Domestic supplu (purchaser)**	**Domestic use**	**Domestic use %**
Coal	243.6	131.4	37.0	412.02	117.8	48.3%
Gas	111.9	66.3	15.0	193.17	55.8	49.9%
Nuclear	345.4	183.5	0.0	528.94	166.9	48.3%
Flow	91.0	59.5	-128.8	21.68	47.9	52.7%
Pumped	16.1	7.2	-6.2	17.16	8.2	50.6%
Wind	145.5	120.4	-322.0	-56.04	75.9	52.1%
Other	39.8	23.9	-17.9	45.75	20.2	50.8%
Non-electricity	64,667					

Source: Author's calculation

Table B.7: Scottish 2012 ElSA Table 7.

Electricity industry	***Full-time employment***	**Part-time employment**	**Total Employment**
Renewable	578	30	608
Non-renewable	1,782	30	1,812
Non-generation	5,742	508	6,250
Total	8,102	568	8,670

Source: Author's calculation

Appendix 2C Comparison of ElSA electricity variable and BEIS for 2012

Table 2C.1: Comparing ElSA with BEIS.

	Scottish ElSA (MWh)	BEIS (MW	Difference (ElSA-BEIS)	Percentage of ElSA val
Net supplied electricity	47,683	47,185	498.1	1.04%
Consumption	28,895	29,311-28,749	-416 - 146	1.44% - 0.51%
NI Exports	2,174	2,162	12	0.55%
England Exports	10,508	10,717	-209	-1.99%
Losses	2,541	2,536	5	0.20%
*Coal**	11,148	11,867	-719	-6.45%
*Gas**	5,346	5,639	-293	-5.48%
*Nuclear**	16,146	17,050	-904	-5.60%
*Flow**	4,446	4,839	-393	-8.84%
*Pumped**	606	610	-3.9	-0.64%
*Wind**	8,148	8,362	-214	-2.63%
*Other**	1,843	2,089	-246	-13.35%

Source: Author's calculation and Scottish ElSA

* The values quoted by BEIS are overall generation where as in the ElSA these are for the electricity delivered to the grid (Net).

Appendix 3A Disaggregated Scottish IO table

Table 3A.1: 2012 Disaggregated Scottish IO table

	COAL	GAS	COK	OTR	P&P	G&C	CCP	IRS	ELE	GC	GG	GN	GH	GON	GOF	GOT	ARG	WAT	CON	OTM	AIR	OTT	SER	*TID*	HH	NP	CG	LG	GFCF	VAL	CHV	NRH	EUK	*ERO*	TDI
COAL	4.8	0.3	1.6	0.4	0.2	0.0	0.3	0.5	0.0	85.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	2.8	0.9	0.0	0.9	2.5	100.8	7.5	0.0	0.0	0.0	2.0	0.0	-39.6	0.5	190.3	4.0	265.6
GAS	5.2	92.1	6.4	51.6	26.9	40.8	53.4	21.8	263.2	11.1	111.9	45.5	15.0	21.0	1.4	5.5	4.5	5.9	141.1	110.3	1.0	13.6	167.3	1,216.5	595.1	0.0	0.0	0.0	8.0	0.0	-1.3	1.7	553.7	98.0	2,471.6
COK	0.4	0.4	3.5	3.8	0.8	0.4	0.2	1.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	2.8	0.3	3.4	12.5	2.8	8.1	11.7	54.0	47.1	0.0	0.0	0.0	2.1	0.0	-11.6	3.7	886.2	824.4	1,805.8
OTR	1.1	3.0	8.4	554.5	22.1	1.4	2.2	11.1	3.3	0.3	0.1	0.4	0.1	0.2	0.0	0.1	84.6	6.2	195.7	235.7	1.8	16.6	484.2	1,633.4	1,728.8	0.0	0.0	0.0	34.6	0.3	-30.2	45.3	4,100.7	3,787.7	11,300.5
P&P	0.4	0.7	4.6	114.5	162.7	3.4	1.3	6.8	2.8	0.3	0.1	0.4	0.1	0.2	0.0	0.0	12.2	1.8	18.8	112.0	0.4	6.1	299.3	748.7	77.1	0.0	0.6	0.0	7.6	0.0	5.8	8.6	347.3	313.5	1,509.2
C&C	0.5	0.8	1.8	43.6	0.1	12.8	0.2	4.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.1	100.8	48.6	0.3	3.0	13.6	235.0	48.9	0.0	0.0	0.0	1.4	0.0	-1.3	2.2	62.0	117.2	465.3
CCP	0.8	8.5	0.3	1.6	0.1	0.7	7.3	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	0.8	198.2	7.1	0.0	2.4	20.3	254.2	4.6	0.0	0.0	0.0	0.3	0.0	-3.4	0.3	22.0	27.8	305.9
IRS	8.8	2.5	25.0	94.5	1.3	4.2	1.0	187.3	12.3	1.2	0.6	1.7	0.5	0.8	0.0	0.2	13.0	3.1	240.1	463.4	1.1	17.5	143.0	1,223.1	106.8	0.0	0.0	0.0	135.9	0.8	-19.8	4.8	806.2	651.7	2,909.5
ELE	20.8	230.1	13.3	144.3	68.7	23.8	10.1	64.3	309.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.2	40.3	82.0	344.1	5.0	54.5	606.6	2,041.6	1,630.5	0.1	0.0	0.0	67.5	0.0	0.7	5.1	1,693.0	35.2	5,473.5
CC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	520.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	520.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	520.6
CG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	247.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	247.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	247.1
CN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	735.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	735.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	735.1
CH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	242.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	242.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	242.9
CON	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	338.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	338.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	338.9
COF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.2
COT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.6
ARG	0.5	0.5	2.1	976.4	11.2	0.3	0.3	0.8	1.2	0.2	0.1	0.2	0.1	0.1	0.0	0.6	384.4	0.3	24.1	41.2	0.3	3.8	132.5	1,581.2	916.3	7.9	0.0	10.7	78.0	0.0	24.0	41.2	803.3	215.1	3,677.7
WAT	0.8	1.5	11.7	98.5	3.9	1.0	0.6	3.9	31.3	0.0	0.0	3.5	0.0	0.0	0.0	0.0	16.2	124.0	6.4	21.7	0.5	4.1	210.5	540.0	807.1	0.0	0.0	0.1	9.6	0.0	1.0	1.8	89.0	109.7	1,558.2
CON	5.9	19.2	5.6	47.1	10.6	1.8	1.7	11.5	18.2	2.1	0.5	5.7	3.5	4.9	0.3	1.2	51.0	40.1	3,487.2	795.0	15.3	108.3	2,188.5	6,825.1	134.2	0.2	0.0	0.0	9,070.5	0.0	42.4	8.8	1,127.4	199.3	17,408.0
OTM	26.1	61.1	186.5	633.4	72.8	22.9	17.7	174.2	96.2	5.4	1.3	14.5	9.0	12.4	0.7	3.1	298.8	44.4	982.8	2,402.7	36.4	277.3	2,021.6	7,401.1	12,816.7	24.8	0.0	32.6	1,595.4	58.8	-88.4	401.6	5,795.1	7,572.7	35,610.4
AIR	0.2	0.5	0.5	2.3	0.3	0.2	0.2	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.1	3.5	19.5	11.0	13.9	80.8	134.7	230.8	0.0	0.0	0.0	5.4	0.0	0.1	2.4	642.5	39.4	1,055.4
OTT	8.8	38.6	10.9	229.8	36.8	13.9	16.8	42.3	9.0	0.9	0.4	1.2	0.4	0.6	0.0	0.1	75.5	22.8	132.0	1,724.1	58.7	1,421.7	1,007.8	4,853.1	1,900.8	0.0	0.0	0.0	92.2	0.0	0.6	81.6	1,217.8	670.1	8,816.3
SET	15.1	61.6	54.8	517.5	63.7	17.7	12.0	148.7	134.2	12.8	6.1	18.0	6.0	8.3	0.5	2.2	224.7	84.7	1,501.8	3,350.6	159.9	973.5	19,883.6	27,258.1	28,997.4	3,259.7	19,255.6	12,012.9	3,051.7	0.8	9.5	1,881.5	18,086.7	7,480.2	121,294.0
TDC	100	521	337	3,514	482	145	125	680	3,077	120	121	93	35	48	3	13	1,202	375	7,120	9,689	294	2,925	27,274	58,296											
IUK	59	1,113	886	2,354	324	92	58	480	861	210	11	183	76	105	6	50	919	120	2,282	5,001	267	1,531	13,419	30,406											
IOW	34	152	173	1,085	138	23	24	424	252	61	3	53	22	31	2	15	233	36	652	3,015	80	462	4,367	11,338											
TIC	193	1,787	1,396	6,952	944	260	207	1,584	4,189	391	135	329	133	184	10	77	2,355	532	10,054	17,706	642	4,919	45,059	100,040											
TL1	10	63	86	170	19	11	5	27	591	37	15	0	-135	-267	-55	-18	52	13	94	318	85	224	2,793	4,139											
TL2	5	27	19	68	14	5	4	31	68	6	3	9	3	4	0	1	-572	24	93	798	12	56	805	1,482											
COE	65	320	138	2,447	390	172	80	1,081	424	14	4	41	8	22	11	5	470	258	4,436	11,302	206	2,490	41,833	66,216											
GOS	-9	275	167	1,664	142	18	10	186	201	72	89	355	234	395	56	24	1,374	732	2,731	5,486	111	1,128	30,804	46,246											
GVA	62	622	324	4,178	546	195	93	1,299	693	92	97	406	245	421	68	29	1,271	1,014	7,260	17,586	329	3,673	73,442	113,944											
TOU	266	2,472	1,806	11,301	1,509	465	306	2,909	5,474	521	247	735	243	339	22	89	3,678	1,558	17,408	35,610	1,055	8,816	121,294	218,122											

Tabe 3A.2: List of variable codes for Scottish IO

Variable	Code
Coal Mining and quarry	COAL
Gas Mining and quarrying	GAS
Coke ovens, refined petroleum and nuclear fuel	COK
Other traded e.g. Food and drink	OTR
Pulp and Paper	P&P
Glass and Ceramics	G&C
Clay, cement, lime and plaster	CCP
Iron and Steel; non-ferrous metals	IRS
Electricity Non Gen	ELE
Generation - Coal	GC
Generation - Gas	GG
Generation - Nuclear	GN
Generation - Hydro	GH
Generation - Onshore Wind	GON
Generation - Offshore Wind	GOF
Generation - Other	GOT
Agriculture; Forestry and fishing	ARG
Water	WAT
Construction	CON
Other Manufacturing and wholesale retail trade	OTM
Air Transport	AIR
Other Transport	OTT
Services	SER
Total domestic consumption	TDC
Imports from rest of UK	IUK
Imports from rest of world	IRO
Total intermediate consumption at basic prices	TIC
Taxes less subsidies on products	TL1
Taxes less subsidies on production	TL2
Compensation of employees	COE
Gross operating surplus	GOS
Gross value added at basic prices	GVA
Total output at basic prices	TOU
Total intermediate demand	TID
Households	HH
NPISHs	NP
Central government	CG
Local government	LG

Gross fixed capital formation	GFCF
Valuables	VAL
Change in inventories	CHV
Non-resident households	NRH
Rest of UK exports	EUK
Rest of world exports	ERO
Total demand for industry output	TDI

Appendix 3B Multiplier analysis

In Chapter 3 the electricity sector in the IO accounts was disaggregated using a bottom-up approach with data gathered from the 2012 Scottish ElSA. A key motivation for undertaking this disaggregation was because each generation technology may have a different multiplier reflecting differences in their connection to the Scottish economy. This section will investigate these multipliers, with the ranked Type 1 and Type 2 multipliers for each industry's used in the IO model found in Table 3B.1 below, these were calculated using the table in Appendix 3A.

Table 3B.1: Output multipliers of disaggregated IO table.

	Type 1	Rank	Type 2	Rank
Electricity Non Gen	**1.75**	**1**	**2.00**	**9**
Gen - Gas	**1.65**	**2**	**1.83**	**15**
Construction	1.61	3	2.26	1
Clay, cement, lime and plaster	1.58	4	2.16	3
Coal Mining and quarrying	1.55	5	2.14	4
Other Transport	1.47	6	2.12	5
Pulp and Paper	1.47	7	2.04	8
Agriculture; Forestry and fishing	1.46	8	1.84	14
Glass and Ceramics	1.45	9	2.17	2
Other traded e.g .Food and drink	1.44	10	1.94	12
Air Transport	1.38	11	1.86	13
Other Manufacturing and wholesale retail trade	1.38	12	2.04	6
Gen - Coal	**1.34**	**13**	**1.52**	**18**
Water	1.34	14	1.72	16
Iron and Steel; non-ferrous metals	1.33	15	2.04	7
Gas Mining and quarrying	1.33	16	1.61	17
Services	1.31	17	1.98	11
Coke ovens, refined petroleum and nuclear fuel	1.26	18	1.49	19
Gen - Other	**1.20**	**19**	**1.36**	**21**
Gen - Hydro	**1.20**	**20**	**1.32**	**22**
Gen - Onshore wind	**1.20**	**21**	**1.37**	**20**
Gen - Offshore wind	**1.18**	**22**	**1.99**	**10**
Gen - Nuclear	**1.17**	**23**	**1.32**	**23**

Source: Author's calculation

Table 3B.1 shows that there is a large variation in both the Type 1 and Type 2 multipliers between the disaggregated electricity sectors and underlines the importance of disaggregating the electricity sector. In Section 3.5.1 it was determined that the non-generation electricity sector and gas generation had high proportions of intermediate inputs, reflected in the Type 1 multipliers. With Type 1 multipliers being used for direct and indirect effects the key determinant is the sales to and purchases from other sectors within the economy. From Table 3B.1, non-generation electricity has the highest ranked multiplier in the 23 sector economy[97] which mirrors the results found in Allan et al (2007). Also as with Allan et al (2007) the multipliers for the disaggregated non-generation sector are similar to the original electricity sector. Explained in the previous chapter this occurs as the non-generation sector acts as the purchaser of the generated electricity which then sells to the other sectors within the economy thus a high level of interconnectivity to the other sectors in the economy. Gas generation is the second highest ranked sector due to the high volume of fuel inputs purchased Scotland.

In the Type 2 case in addition to the effect of the supply chain effects another key determinant is the household income (i.e wages). Changes in income impacts on the household's consumption of goods and services, the induced effects. For most of the disaggregated electricity sectors, excluding offshore wind, the increase in the multipliers from Type 1 to Type 2 is not as large as in the rest of the economy. The non-electricity generation sector ranks drops from 1 to 9 while gas generation is now ranked 15 compared with the Type 1 rank of 2. This occurs as most of the electricity sectors are not labour intensive- other multipliers can also be calculated based on GVA and employment. For offshore wind the increase in the multiplier occurs because there are a high level of employees for a small output[98].

[97] As detailed later in the chapter there as a need to aggregate the full Scottish IO to match with the data available.
[98] The output of offshore wind was the lowest out of all the disaggregated generation technologies.

Appendix 4A – Sectoral breakdown of IO model

Table 4A.1: Breakdown of sectoral aggregation in IO model.

Aggregated sector	Original 98 Sectoral code
Coal Mining and quarry	5
Gas Mining and quarrying	6, 35.2
Coke ovens, refined petroleum and nuclear fuel	7, 19
Other traded e.g. Food and drink	10.1-17
Pulp and Paper	17
Glass and Ceramics	23
Clay, cement, lime and plaster	23
Iron and Steel; non-ferrous metals	24-25
Electricity Non Gen	**35.1**
Generation - Coal	**35.1**
Generation - Gas	**35.1**
Generation - Nuclear	**35.1**
Generation - Hydro	**35.1**
Generation - Onshore Wind	**35.1**
Generation - Offshore Wind	**35.1**
Generation - Other	**35.1**
Agriculture; Forestry and fishing	1-3
Water	36-39
Construction	41-43
Other Manufacturing and wholesale retail trade	20-22,24-33,45-47
Air Transport	51
Other Transport	49-50, 52
Services	9, 53-97

Appendix 5A – Sectoral breakdown of CGE model

Table 5A.1: Breakdown of sectoral aggregation in CGE model.

Aggregated sector	Original 98 Sectoral code
Primary	1-3,6-9
Manufacturing	10-18, 20-33, 45-47
Utilities and transport	36-39, 49-52
Services	53-97
Coal	5
Oil	7,19
Gas	35.2
Electricity Non Gen	35.1
Generation - Coal	35.1
Generation - Gas	35.1
Generation - Nuclear	35.1
Generation - Hydro	35.1
Generation - Onshore Wind	35.1
Generation - Offshore Wind	35.1
Generation – Landfill	35.1
Generation – Marine	35.1

Appendix 5B – Scottish Income expenditure account 2012

Table 5B.1: Income-Expenditure Accounts for Scotland in 2012 (£m)

Households				
Income	127,495		*Expenditure*	127,495
Income from Employment	66,216		*IO Expenditure*	85,204
Profit Income (OVA)	7,740		*Payments to Corporations*	13,558
Income from Corporations	23,039		*Payments to Government*	22,399
Income from Government	22,179		*Transfers to RUK*	228
Transfers from RUK	5,704		*Transfers to ROW*	114
Transfers from ROW	2,618		*Payments to Capital*	5,992
Mixed and Proport. Income Unalloc.	7,426		*Total Expenditure*	127,495
Total Household Income	127,495			
Corporations				
Income	61,093		*Expenditure*	61,093
Profit Income (OVA)	33,111		*Payments to Households*	23,039
Income from Households	13,558		*Payments to Government*	6,655
Income from Government	2,038		*Transfers to RUK*	3,969
Income from RUK	6,193		*Transfers to ROW*	4,802
Income from ROW	6,193		*Payments to Capital*	22,628

Governments				
Income	65,876		*Expenditure*	65,876
Profit income (OVA)	5,395		*IO Expenditure*	31,312
Net Commodity Taxes	16,751		*Payments to Corporations*	2,038
Income from Households	22,399		*Payments to Households*	22,179
Income from Corporations	6,655		*Transfers to RUK*	9,565
Income from RUK	14,676		*Payments to Capital*	782
Total Gov Income Balancing Total	65,876		*Total Gov Exp Balancing Total*	65,876
Capital				
Income	21,885		*Expenditure*	21,885
Households	5,992		*IO Expenditure*	21,885
Corporate	22,628			
Government	782			
RUK/ROW	-7,518			
External				
RUK Income from Scotland	63,177		*RUK Expenditure in Scotland*	62,997
Goods & Services from RUK	49,415		*Goods & Services to RUK*	36,423
Transfers to RUK	13,762		*Transfers from RUK*	26,574
ROW Income from Scotland	26,573		*ROW Expenditure in Scotland*	30,956

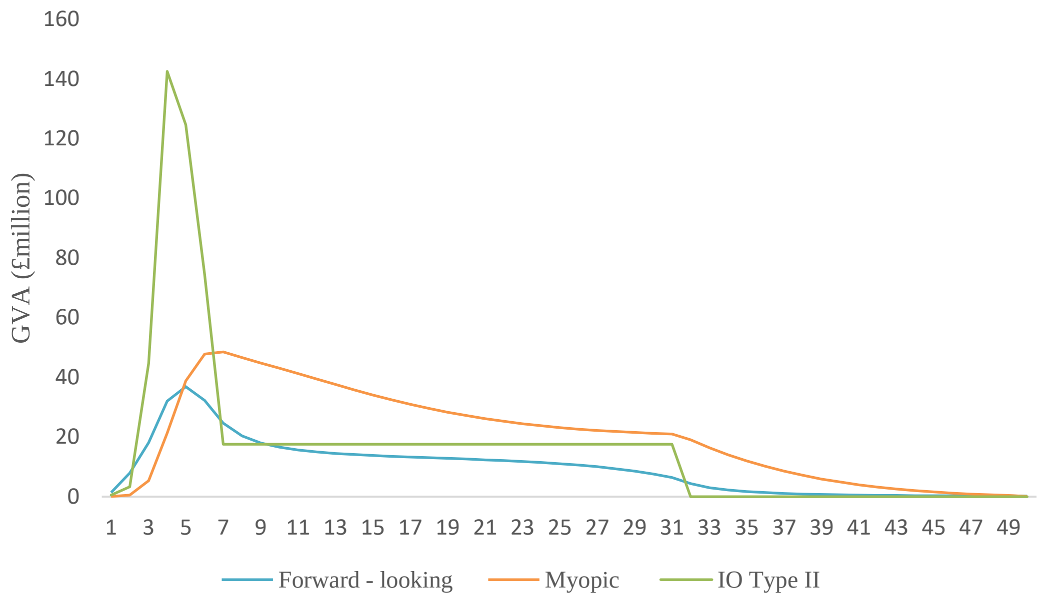
Goods & Services from ROW	21,656		*Goods & Services to ROW*	22,146
Transfers to ROW	4,917		*Transfers from ROW*	8,811
			Tourist Expenditure in Scotland	3,314
Total Income	89,750		*Total Expenditure*	97,268
			Surplus/Deficit	-7,518
		G&S Trade Balance		
RUK	-12,992		*RUK*	1,809
ROW	489		*ROW*	5,709
			Total BOP	7,518
		External Balances		
RUK Total Flows Balance	180			
ROW Total Flows Balance	-4,383			
Tourist Balance	-3,314			
RUK/ROW Surplus/(Deficit), Lending/(Borrowing) with Scotland	-7,518			

Source: Author's calculation

Appendix 5C – Results from CGE modelling non included in main body

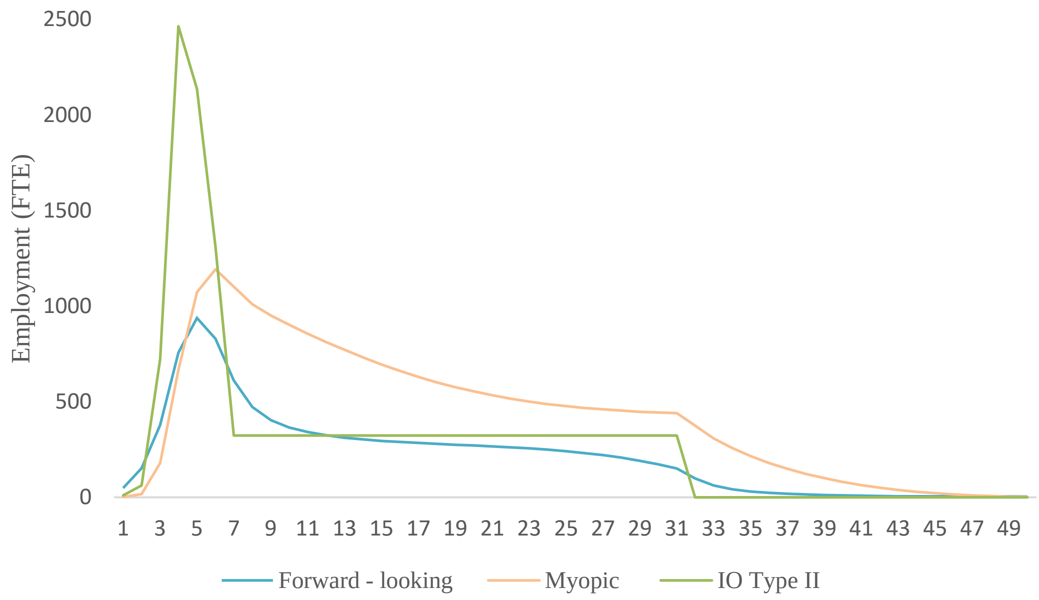
5C.1 Single wind farm (high content)

Figure 5C.1: Single wind farm (high content) GVA/GRP.



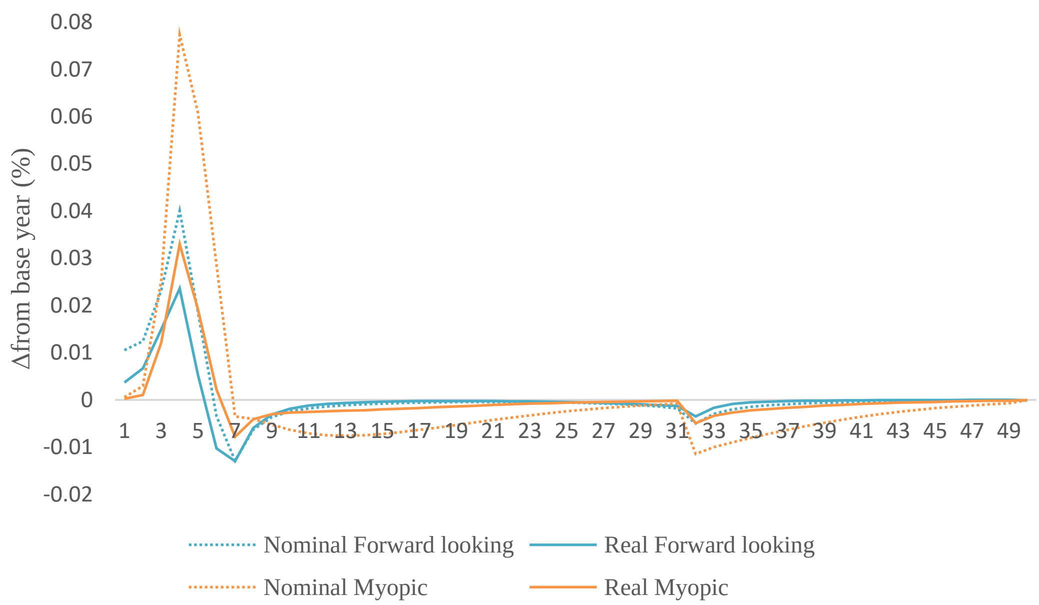
Source: Author's calculation

Figure 5C.2: Single wind farm (high content) Employment.



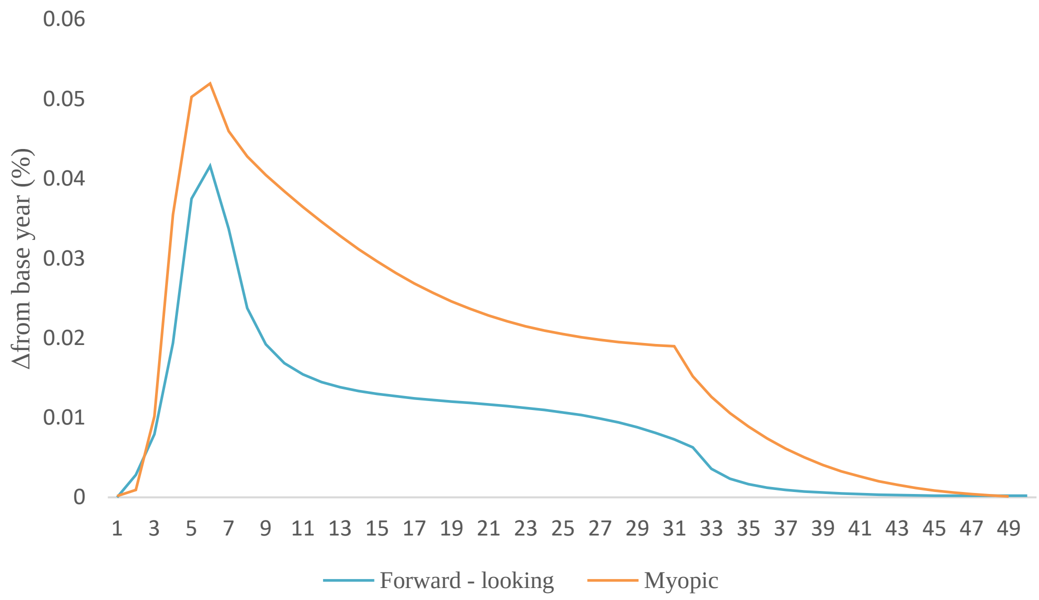
Source: Author's calculation

Figure 5C.3: Single wind farm (high content) Wage rate.



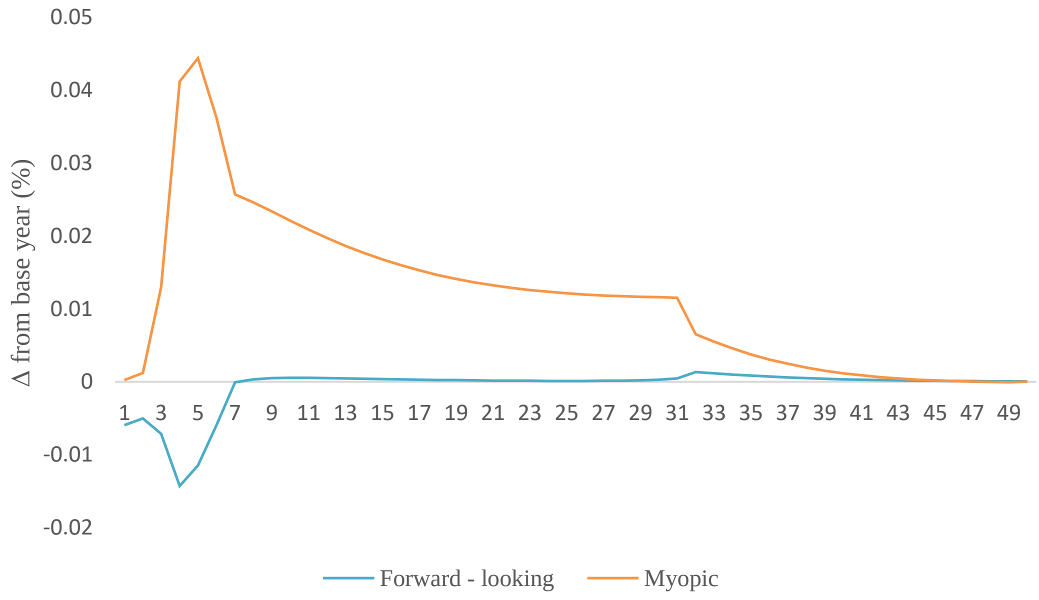
Source: Author's calculation

Figure 5C.4: Single wind farm (high content) Labour supply.



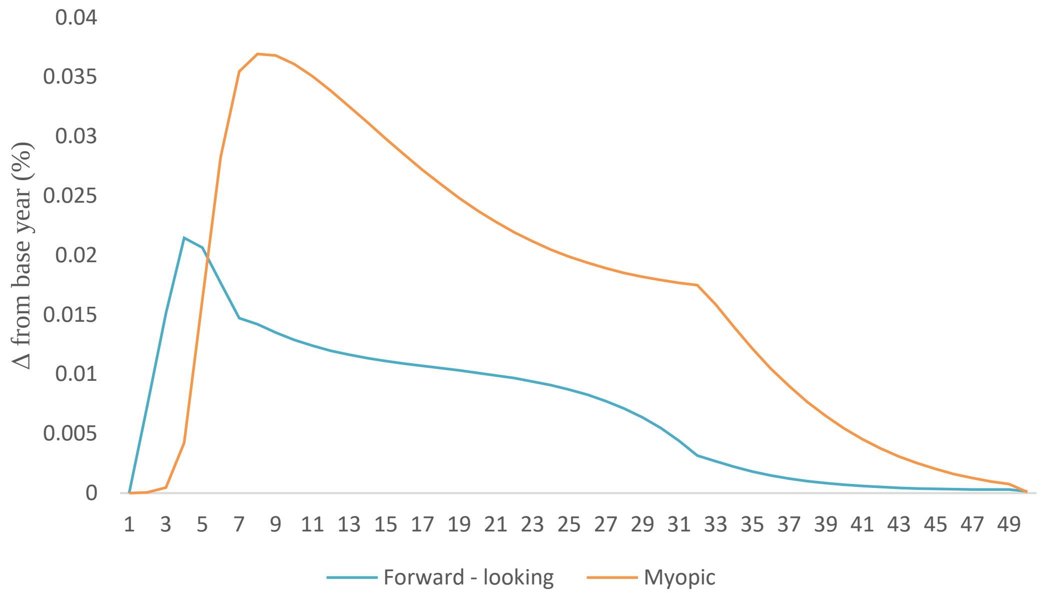
Source: Author's calculation

Figure 5C.5: Single wind farm (high content) Household consumption.



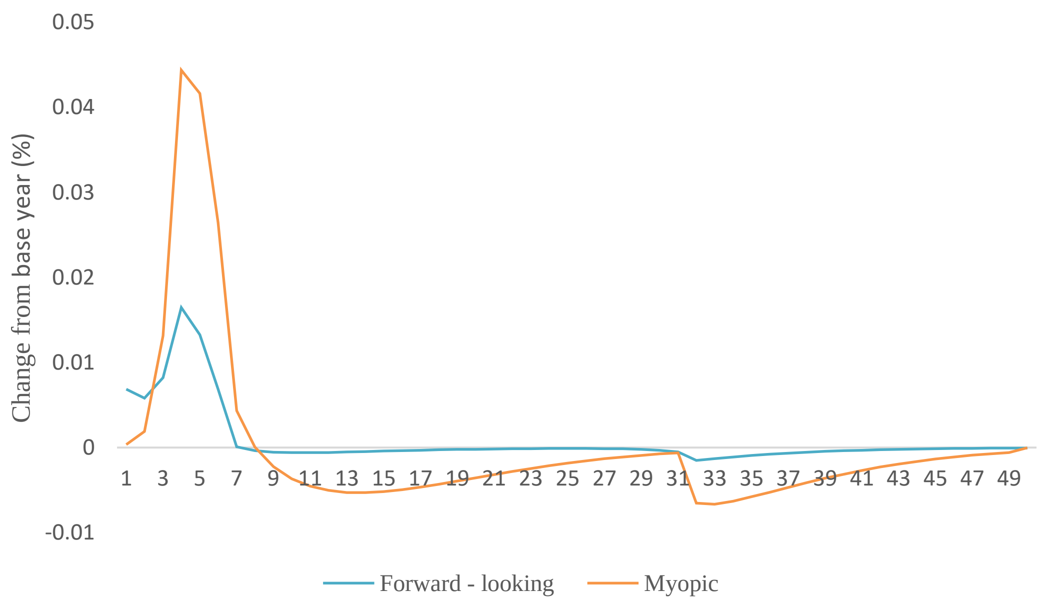
Source: Author's calculation

Figure 5C.6: Single wind farm (high content) Capital stock.



Source: Author's calculation

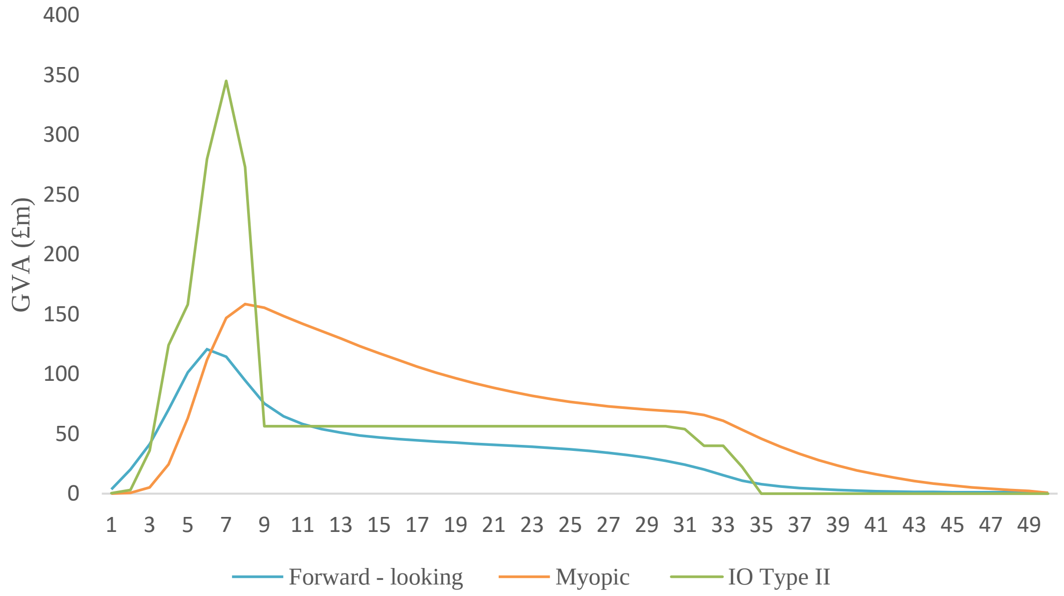
Figure 5C.7: Single wind farm (high content) CPI.



Source: Author's calculation

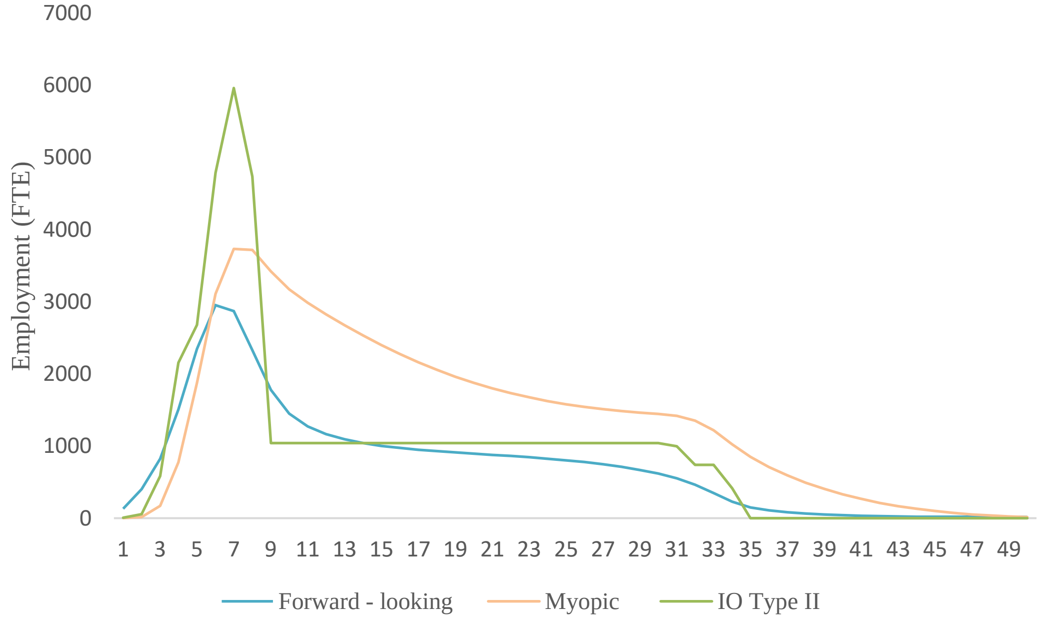
5C.2 Planned capacity (low content)

Figure 5C.8: Planned capacity (low content) GVA/GRP.



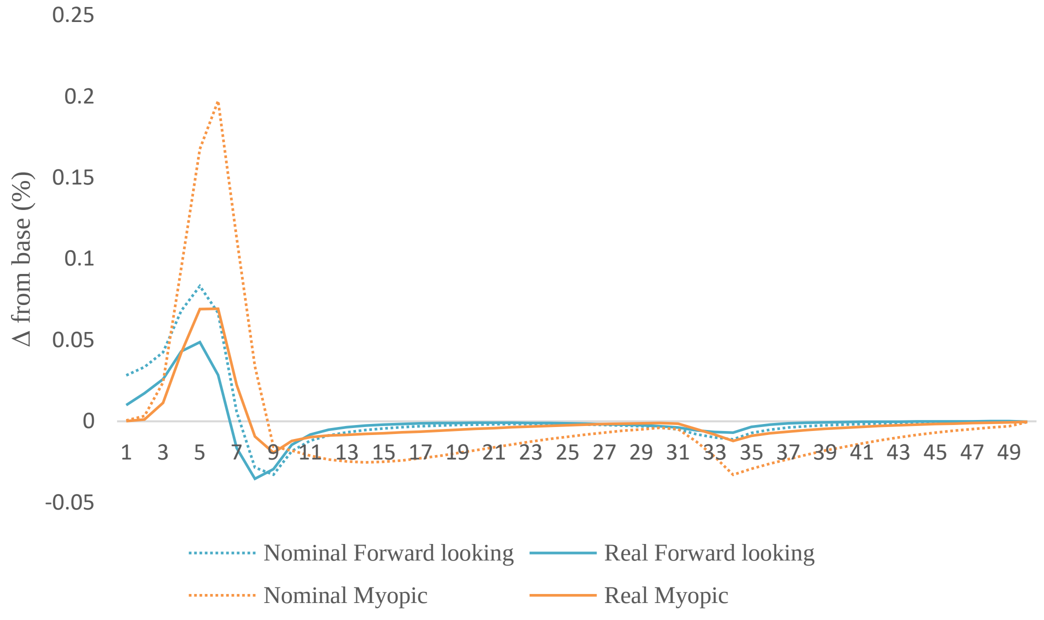
Source: Author’s calculation

Figure 5C.9: Planned capacity (low content)) Employment.



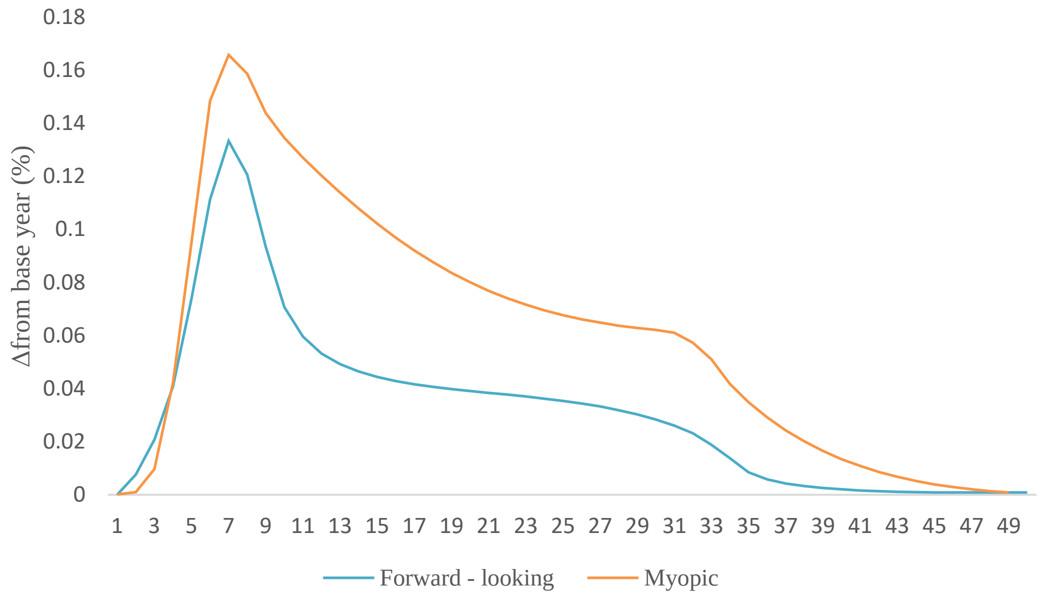
Source: Author’s calculation.

Figure 5C.10: Planned capacity (low content) Wage rate.



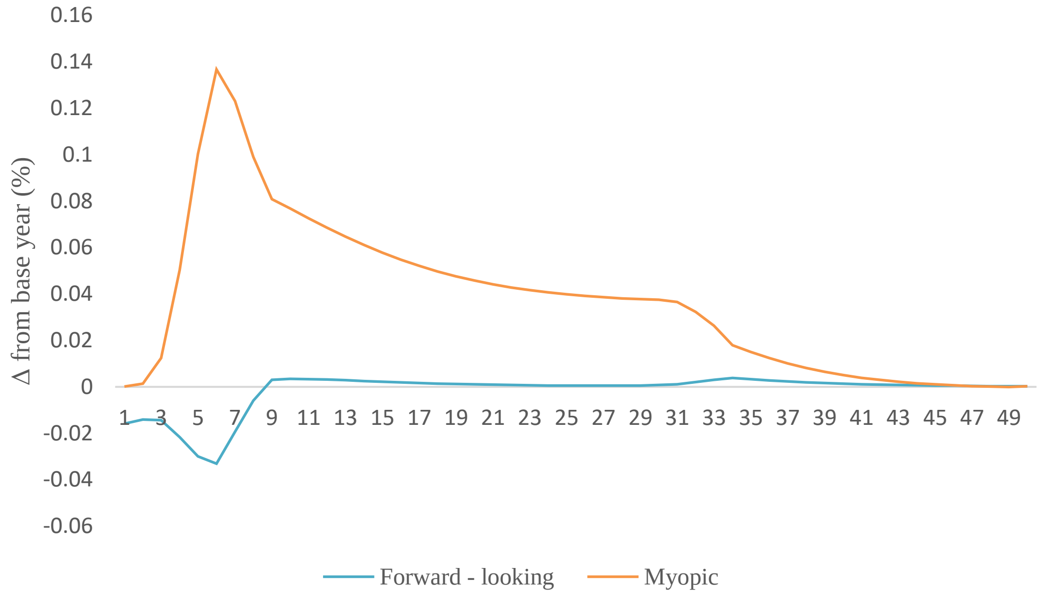
Source: Author's calculation

Figure 5C.11: Planned capacity (low content) Labour supply.



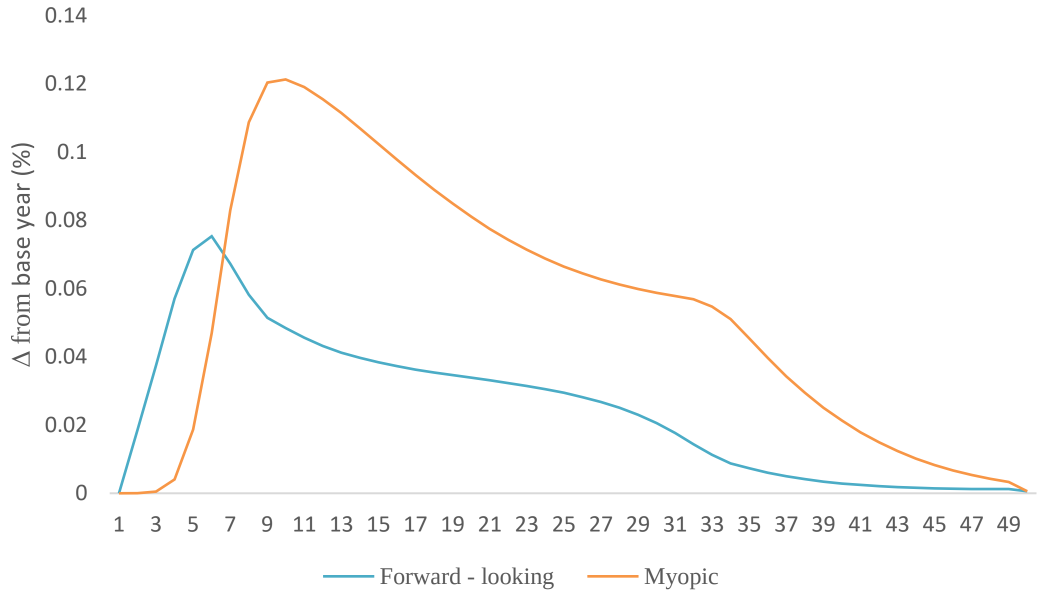
Source: Author's calculation

Figure 5C.12: Planned capacity (low content) Household consumption.



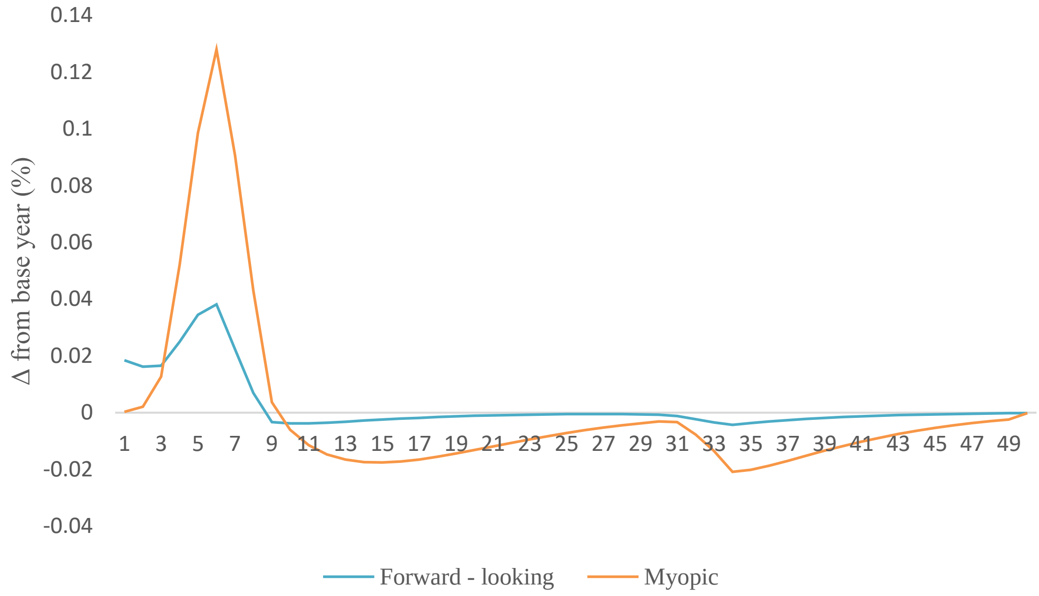
Source: Author's calculation

Figure 5C.13: Planned capacity (low content) Capital stock.



Source: Author's calculation

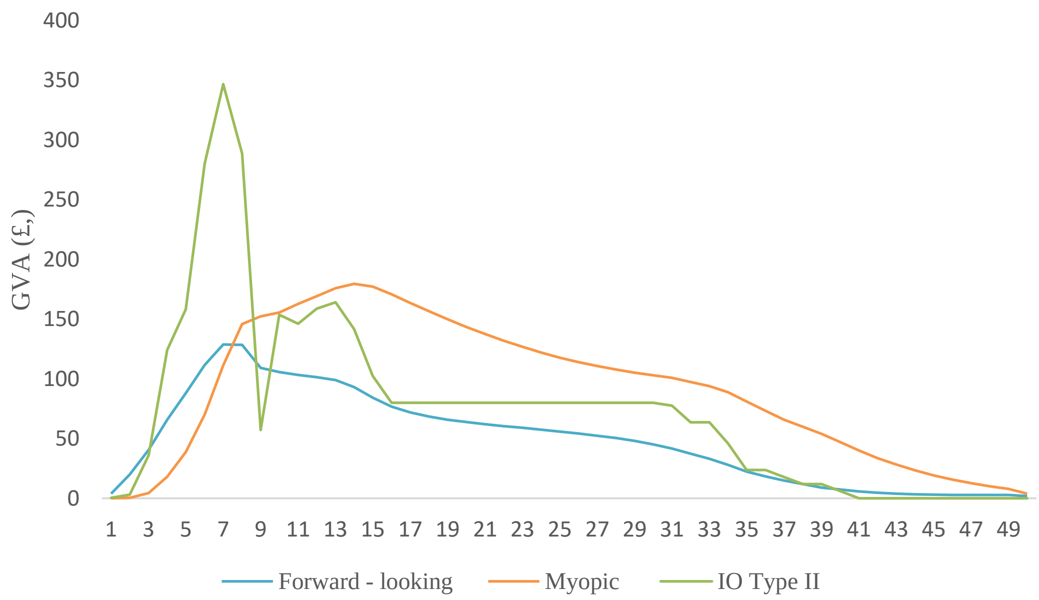
Figure 5C.14: Planned capacity (low content) Household CPI .



Source: Author's calculation

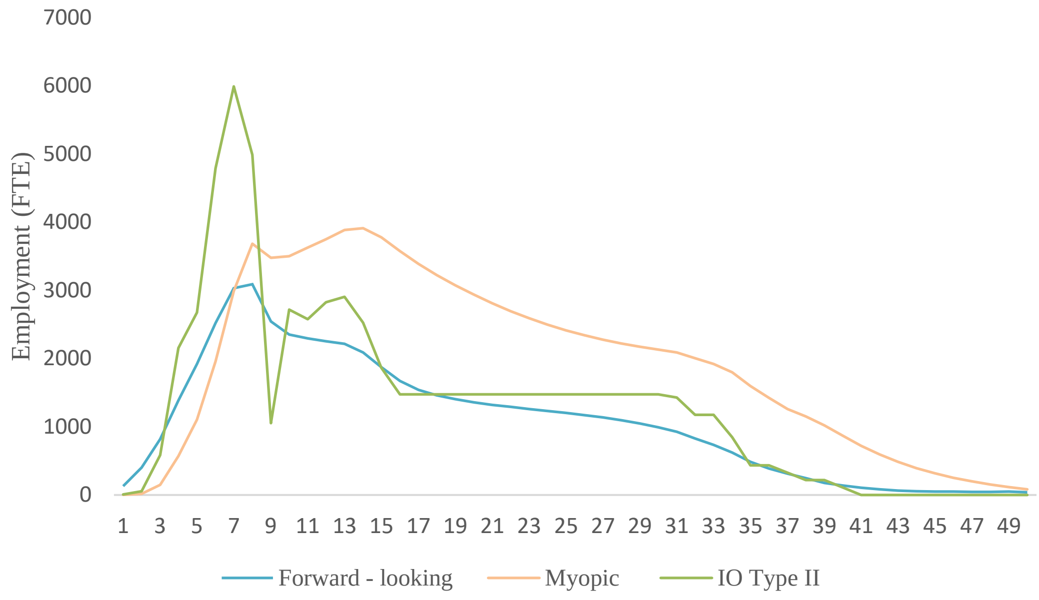
5C.3 Planned capacity with gradual growth (low content)

Figure 5C.15: Planned capacity with gradual growth (low content) GVA/GRP.



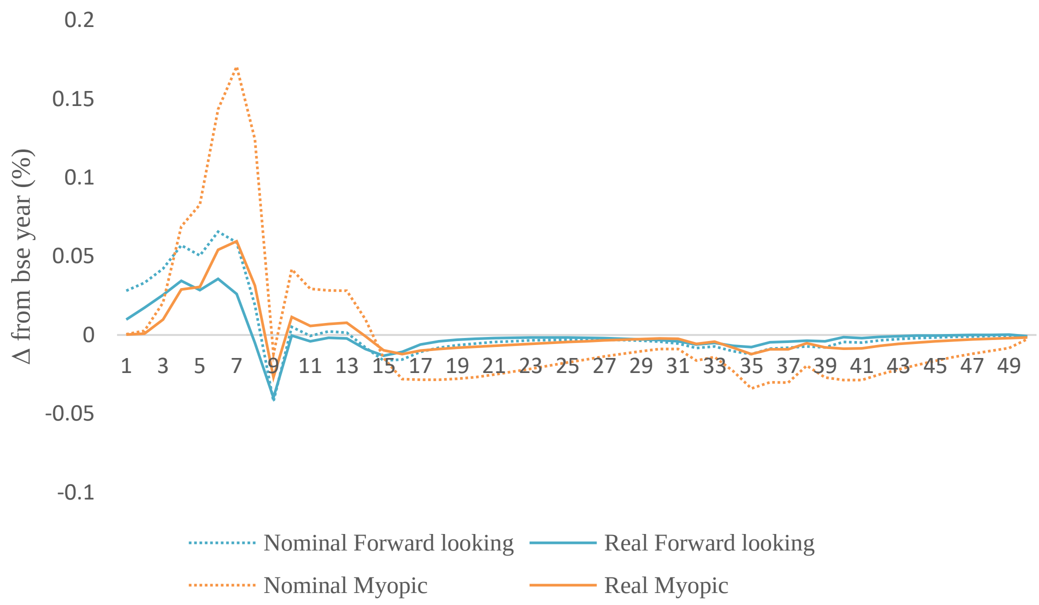
Source: Author's calculation

Figure 5C.16: Planned capacity with gradual growth (low content)) Employment.



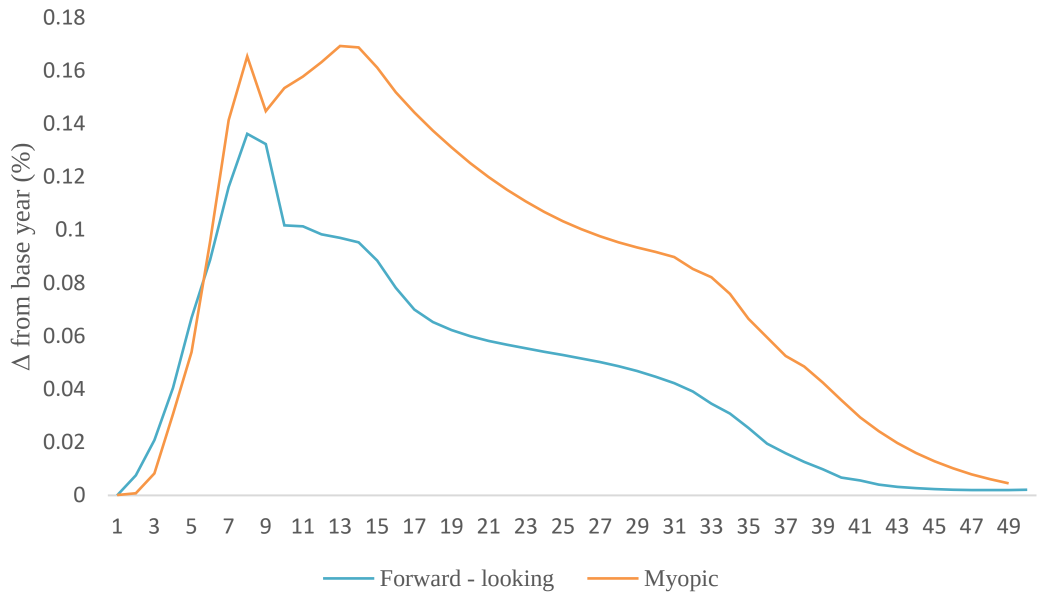
Source: Author's calculation

Figure 5C.17: Planned capacity with gradual growth (low content) Wage rate.



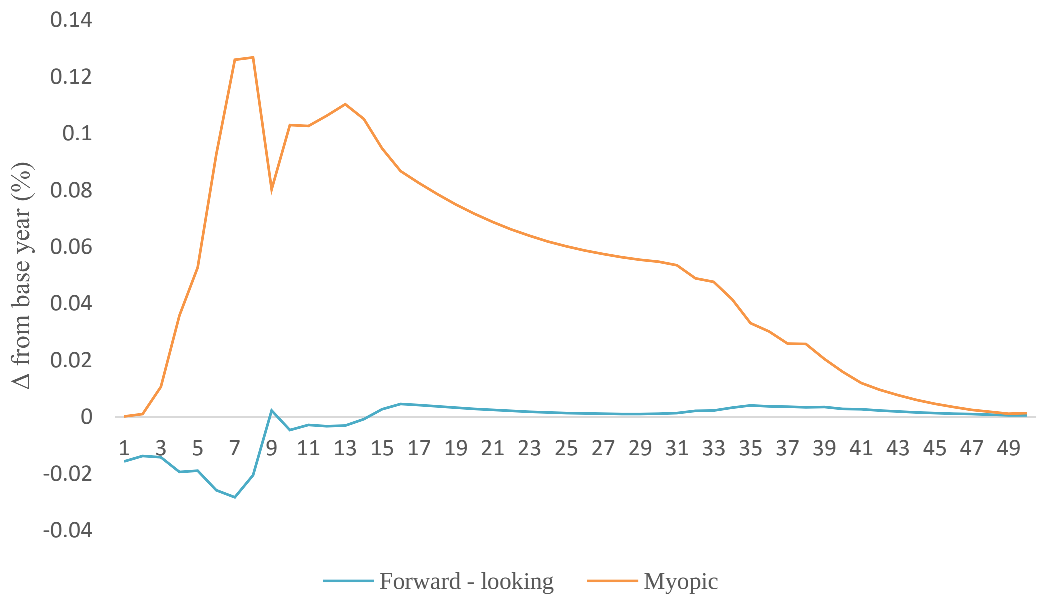
Source: Author's calculation

Figure 5C.18: Planned capacity with gradual growth (low content) Labour supply.



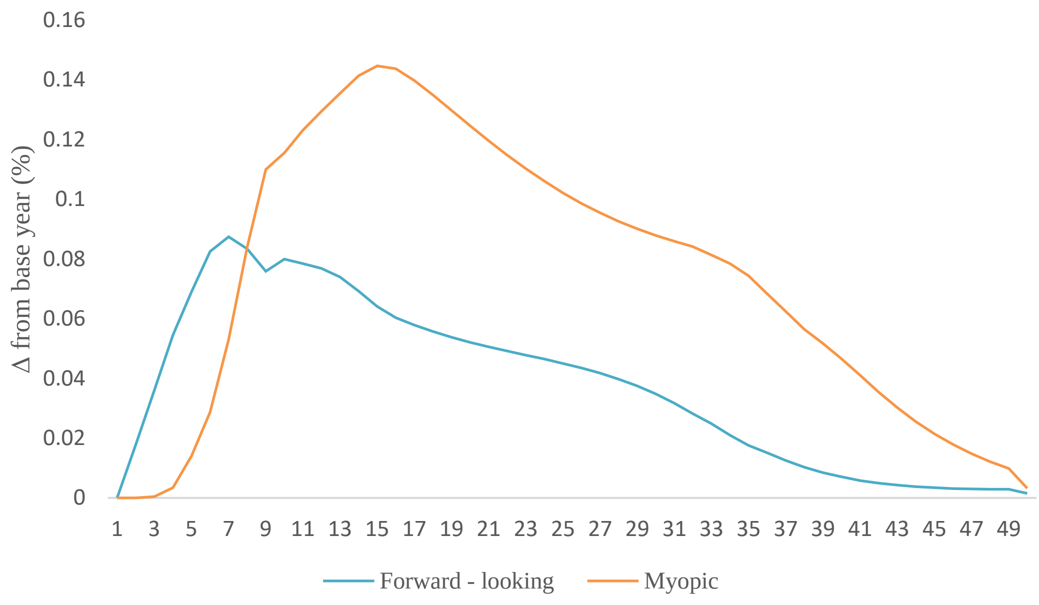
Source: Author’s calculation

Figure 5C.19: Planned capacity with gradual growth (low content) Household consumption.



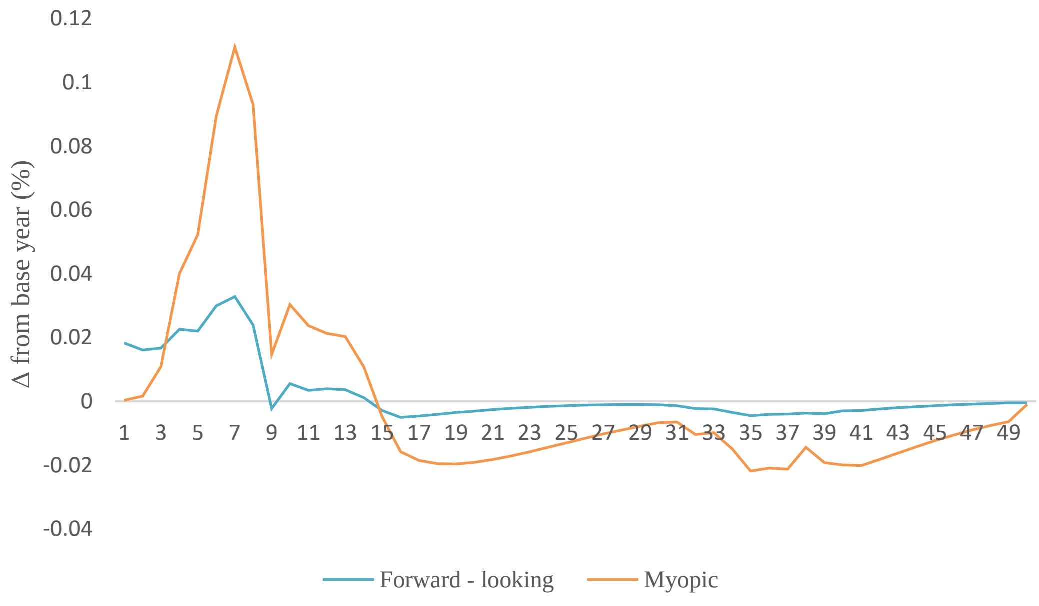
Source: Author’s calculation

Figure 5C.20: Planned capacity with gradual growth (low content) Capital stock.



Source: Author's calculation

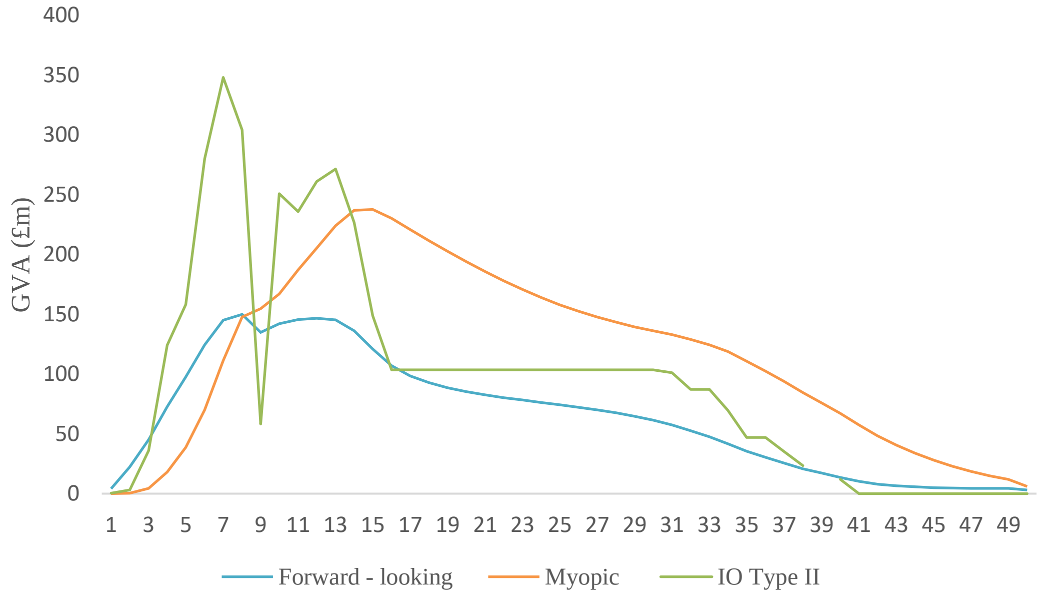
Figure 5C.21: Planned capacity with gradual growth (low content) CPI.



Source: Author's calculation

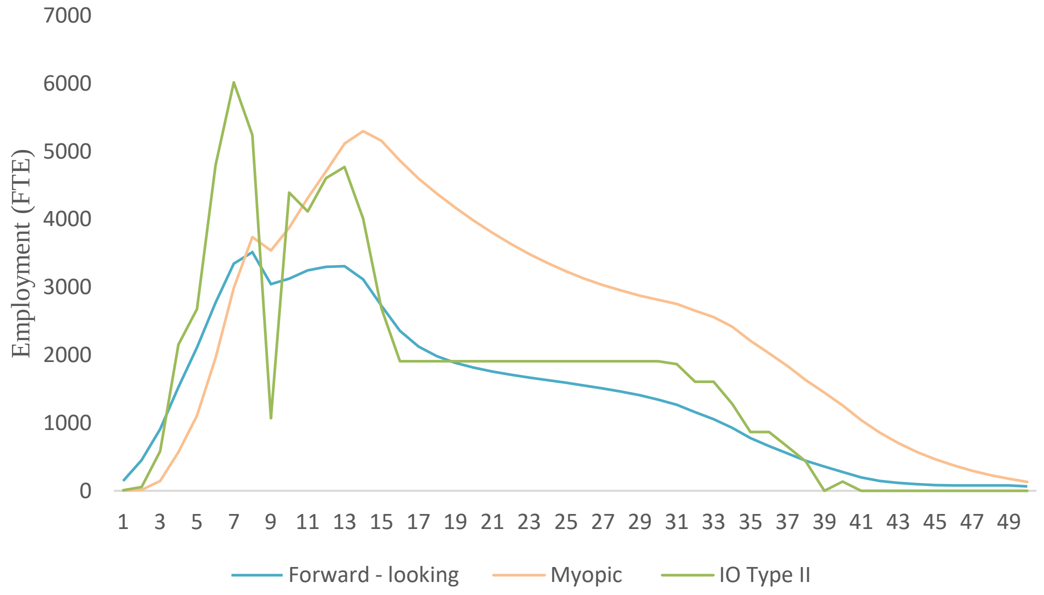
5C.4 Planned capacity with accelerated growth (low content)

Figure 5C.22: Planned capacity with accelerated growth (low content) GVA/GRP.



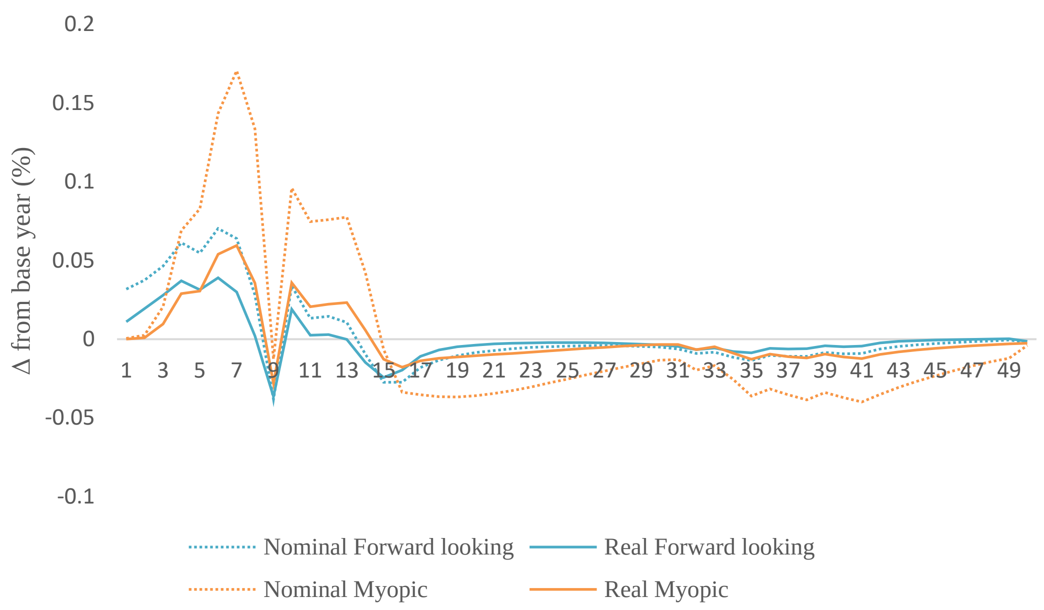
Source: Author's calculation

Figure 5C.23: Planned capacity with accelerated growth (low content)) Employment.



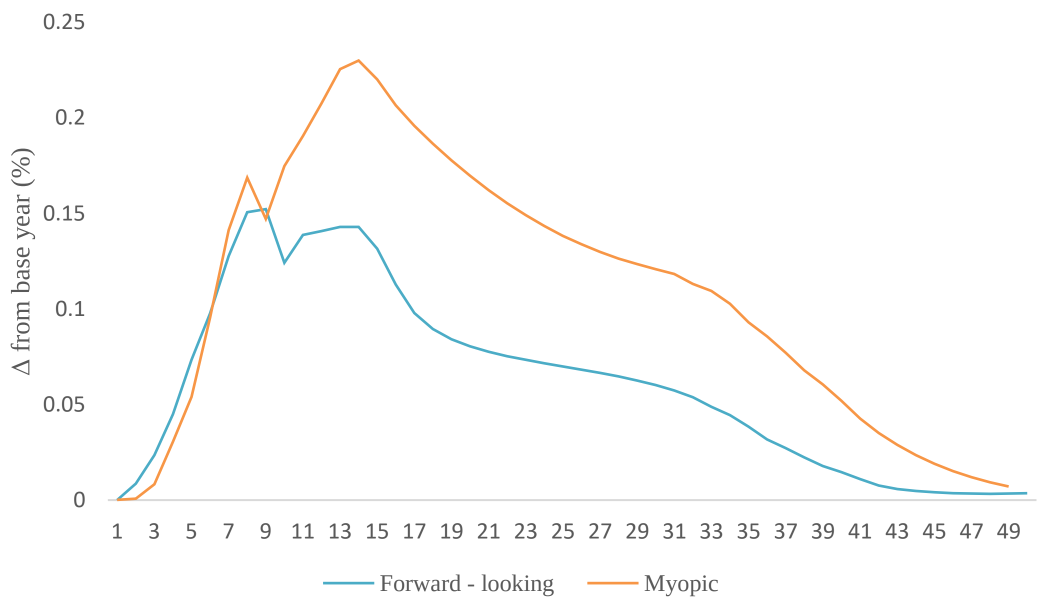
Source: Author's calculation

Figure 5C.24: Planned capacity with accelerated growth (low content) Wage rate.



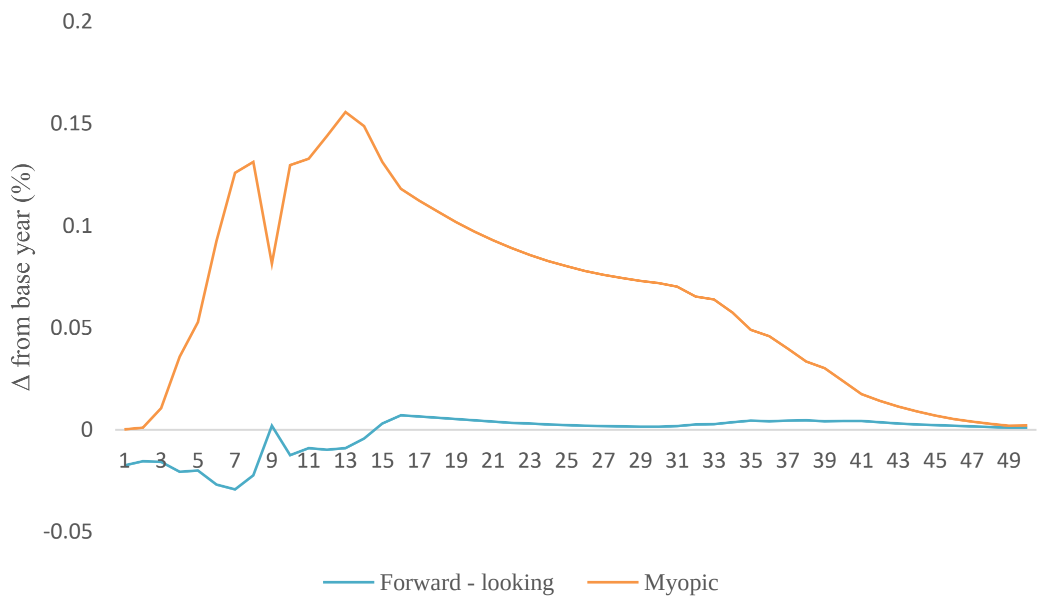
Source: Author's calculation

Figure 5C.25: Planned capacity with accelerated growth (low content) Labour supply.



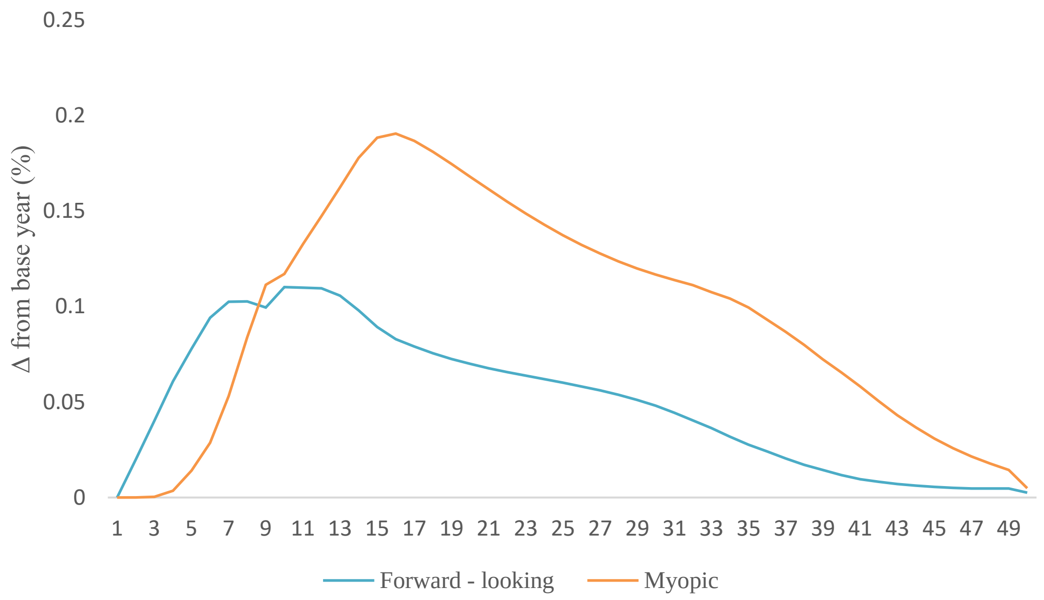
Source: Author's calculation

Figure 5C.26: Planned capacity with accelerated growth (low content) Household consumption.



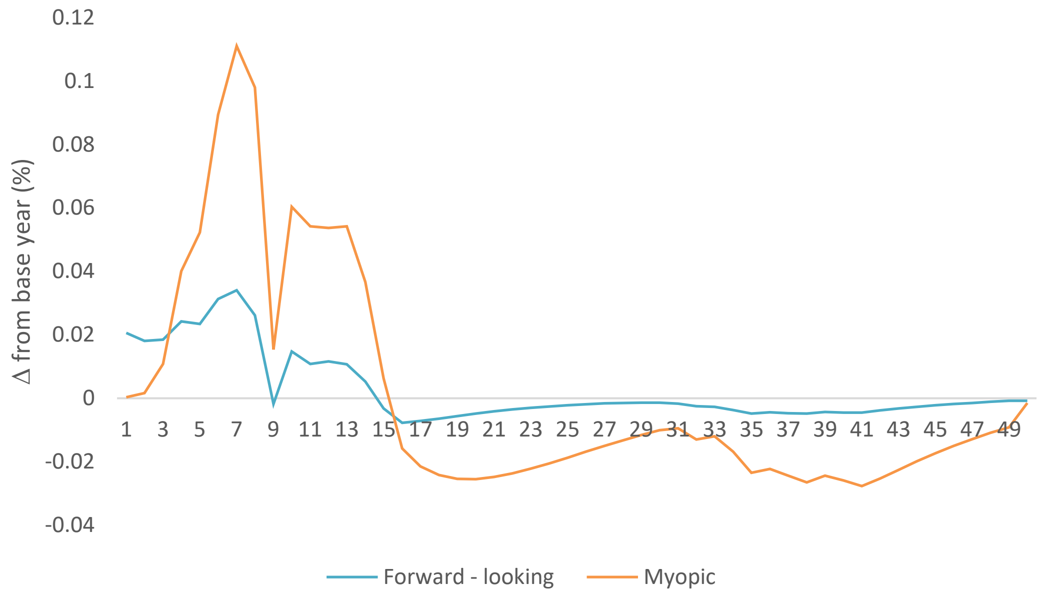
Source: Author’s calculation

Figure 5C.27: Planned capacity with accelerated growth (low content) Capital stock.



Source: Author’s calculation

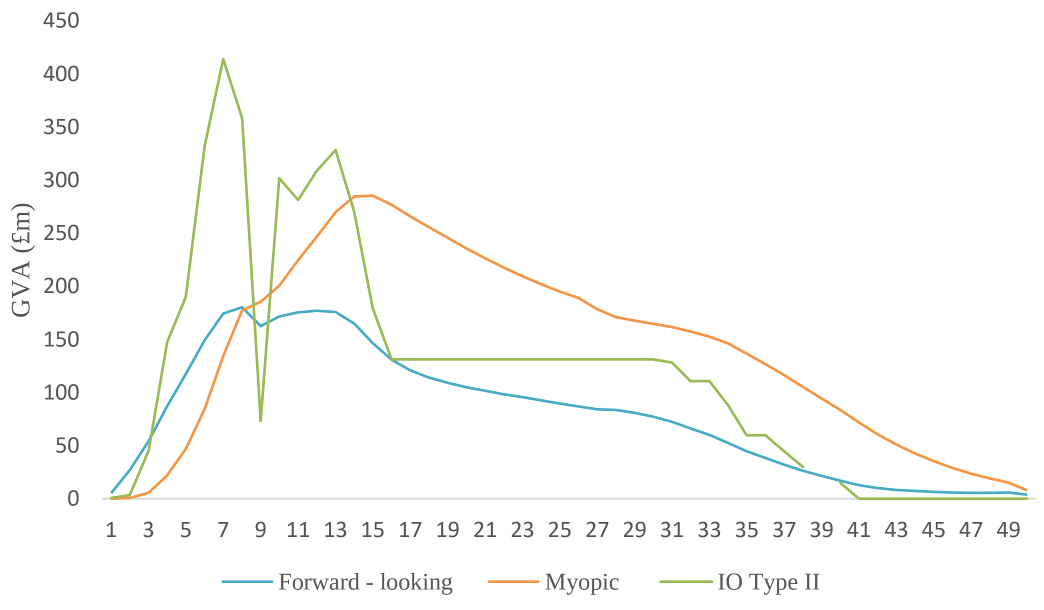
Figure 5C.28: Planned capacity with accelerated growth (low content) CPI.



Source: Author's calculation

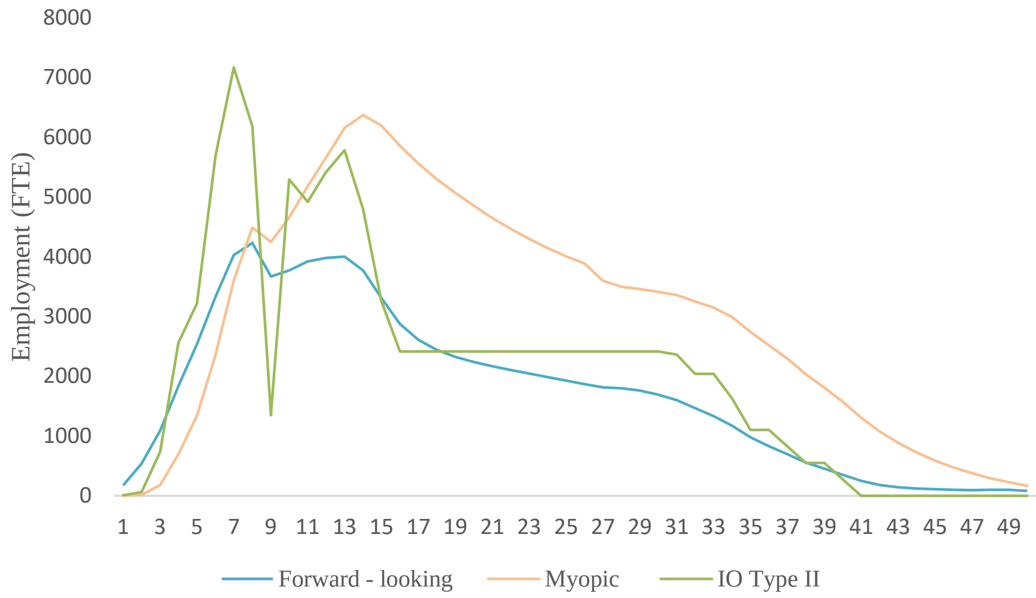
5C.5 Planned capacity with accelerated growth (high content)

Figure 5C.29: Planned capacity with accelerated growth (high content) GVA/GRP.



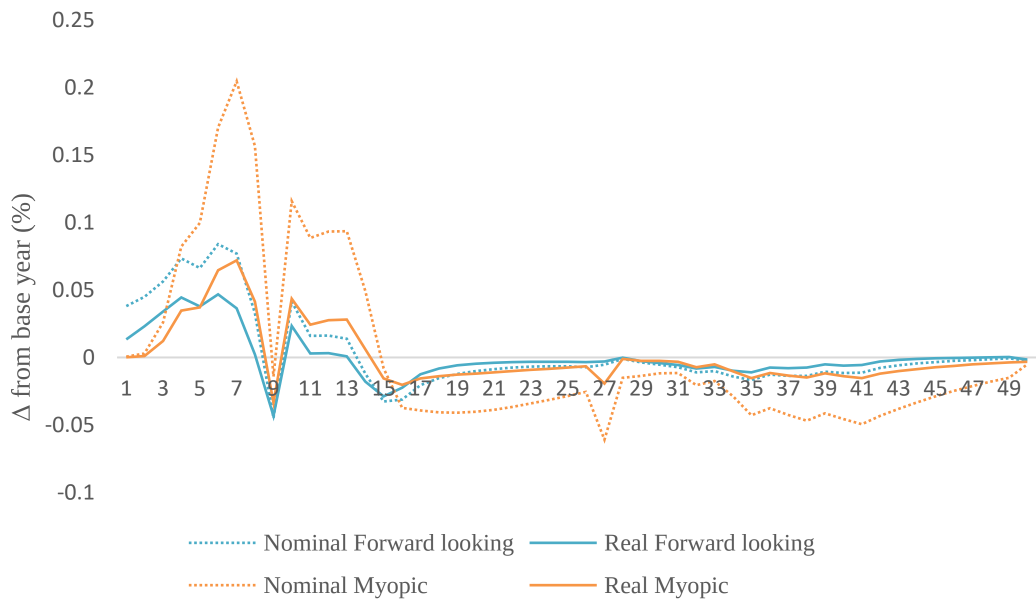
Source: Author's calculation

Figure 5C.30: Planned capacity with accelerated growth (high content)) Employment.



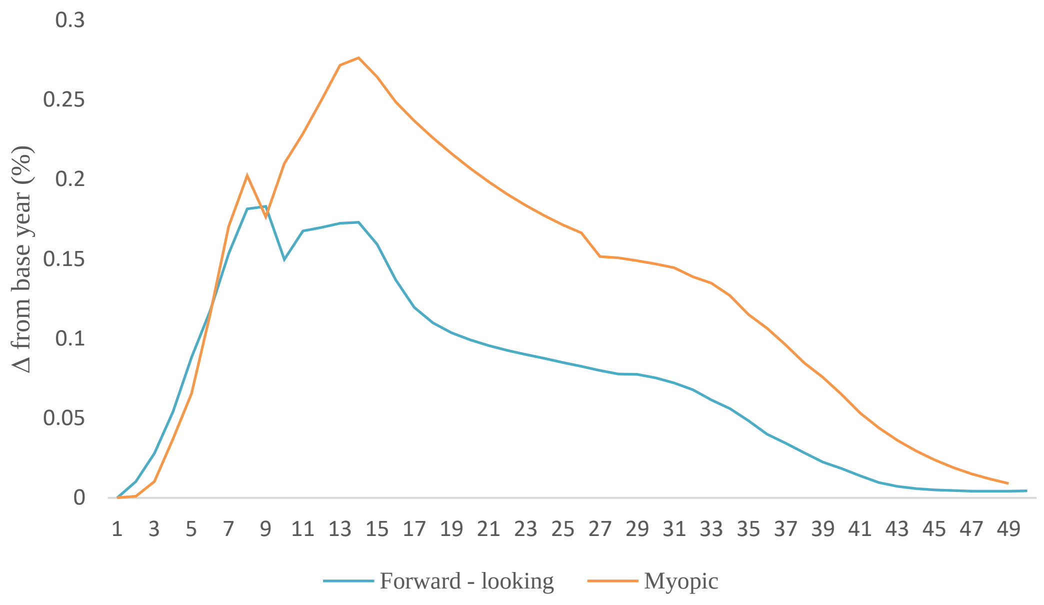
Source: Author's calculation

Figure 5C.31: Planned capacity with accelerated growth (high content) Wage rate.



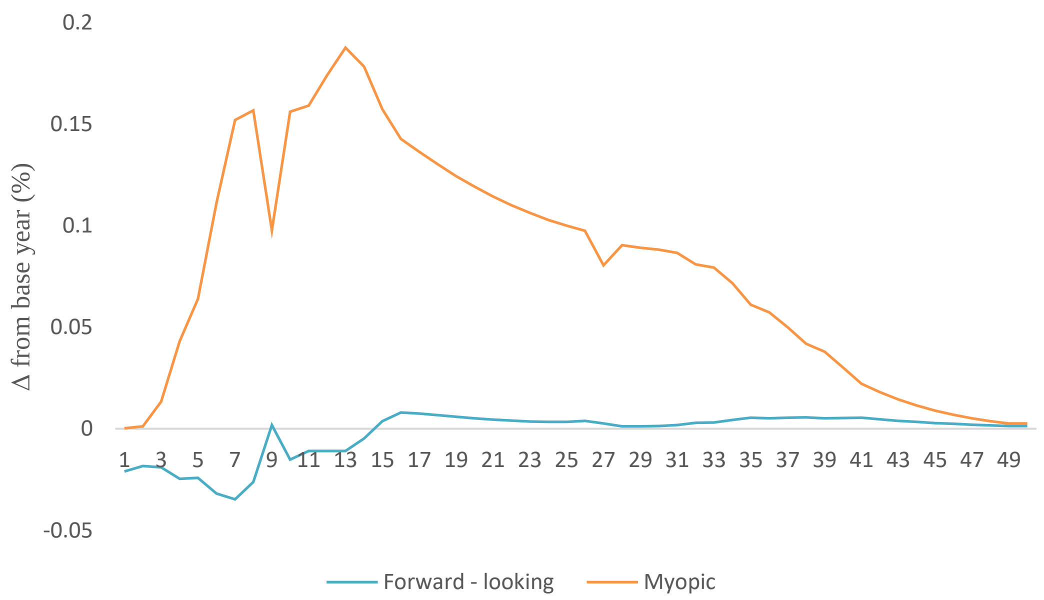
Source: Author's calculation

Figure 5C.32: Planned capacity with accelerated growth (high content) Labour supply.



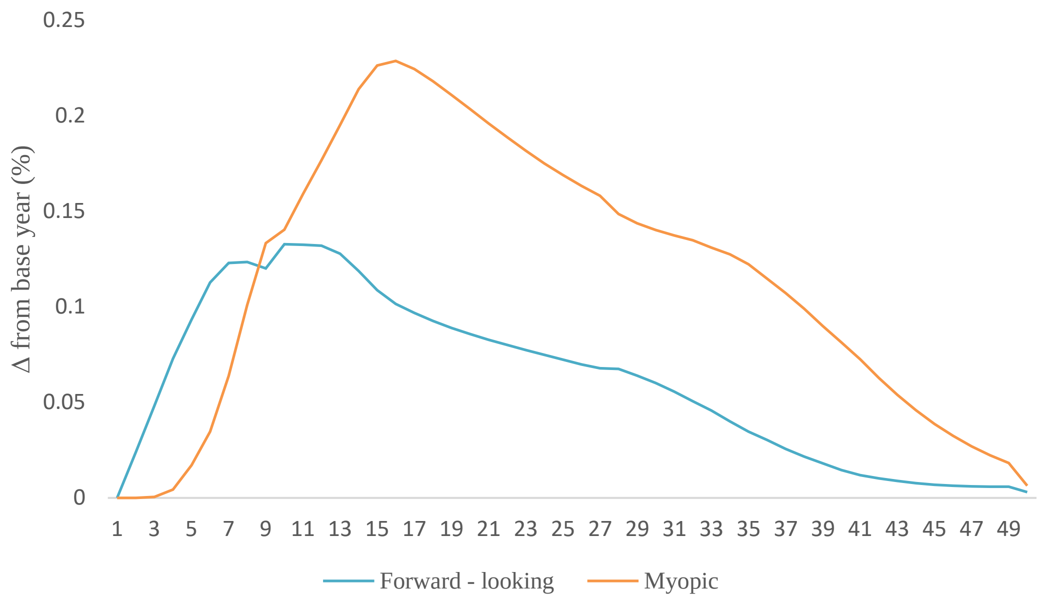
Source: Author's calculation

Figure 5C.33: Planned capacity with accelerated growth (high content) Household consumption.



Source: Author's calculation

Figure 5C.34: Planned capacity with accelerated growth (high content) Capital Stock.



Source: Author's calculation

Figure 5C.35: Planned capacity with accelerated growth (high content) CPI.

Source: Author's calculation