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Scoping the potential use of macroeconomic models to energy policies questions in Northern Ireland

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Introduction

The new Northern Ireland Energy Strategy was published in December 2021 with the primary objective to be net-zero carbon by 2050, and an intermediate target of a 56% reduction in energy related emissions by 2030. The plan sets out a non-exhaustive list of 22 actions to be carried out by the central government, such actions include funding a £10m Green Innovation Challenge and publish an Electric Vehicle (EV) infrastructure action plan. A key element of the Energy Strategy is the Energy Evidence Programme. The evidence programme aims to produce additional evidence to support policy development and identifies a set of key research areas and principles.

Northern Ireland Policy Landscape-Objectives

Published in June 2022, the latest Energy in Northern Ireland publication[1] (Department for the Economy, 2022a) reports on the energy sector in 2020/21. The report notes that Northern Ireland is well on its way to achieving the target of 70% renewable electricity consumption by 2030 with 41.3% produced in 2021[2]. Over recent years there has been a steady increase in renewable electricity, the vast majority of which (82.1% in 2021) is from wind. Gas is the other main fuel source used in electricity generation (42.5% in 2021) with the rest of demand met by other fuels and imports. Northern Ireland is connected to two nations – the Republic of Ireland and Scotland - and is a net importer of electricity.

The energy report also focuses on overall energy consumption, and this will become even more important with the 2050 net zero targets. Over the 10-year period between 2012 and 2021 there was an 6.8% reduction in electricity consumption across Northern Ireland but there were large variations in average consumption by council area. During this period there has also been significant reduction in other fossil fuel use (coal, petrol, manufactured fuels,) across all consumers (domestic, commercial and industrial). Gas is the outlier fossil fuel as there has been an increase in consumption over the 10-year period, driven by an increased number of connections and it's use as a replacement of 'dirtier' fossil fuels such as coal. The use of bio energy and waste as an alternative fuel source has more than doubled in the period.

In addition to the physical use of energy, the report contains information on linkages between energy in Northern Ireland and the economy. Based on the Low Carbon and Renewable Energy (LCRE) survey, the energy sector in Northern Ireland between 2018-2020 had an estimated annual turnover of around £1 billion and generated 5,000 direct FTE jobs through business activity. From the LCRE survey, during the three-year period, Northern Ireland generated 2.2% of UK energy turnover and provided 2.5% of employment in the sector. Energy efficiency production was the largest group of energy activity in both terms of turnover and employment, accounting for 34.6% of turnover and 51% of employment in the Northern Ireland energy sector.

Due to the nature of the LCRE survey, the results may not fully represent the energy sector in Northern Ireland thus the Energy in Northern Ireland 2020 report supplements the LCRE by reporting on the results of analysing the energy sector using SIC groups. Using this method, it was found that in 2019 around 2,976 employee jobs were in the energy sector which is equivalent to 0.38% of all employee jobs in Northern Ireland. This 0.38% was the lowest proportion of all UK nations: England (0.92%), Scotland (2.7%) and Wales 1.3%. The analysis of SIC codes also found that between 2011-2021 the number of energy enterprises had more than tripled from 260 to 905, driven by new enterprises in the 'Electricity, gas, steam and air conditioning supply' sector'. Gross Value Added (GVA) per head in Northern Ireland was also found to be round five times higher for businesses operating in this sector compared with all other sectors on average.

1 Energy in Northern Ireland 2022
2 This has risen further to 47.1% over the 12 months to June 22 (Department for the Economy, 2022b)

In December 2021 (Northern Ireland Executive, 2021) the new energy strategy was published outlining a roadmap with the goal of delivering a 56% decrease in emissions in Northern Ireland by 2030, an action plan (Northern Ireland Executive, 2022) to reach the goal was published in the first half of 2022. Both recognise the need for change in the energy system as there are only 28 years left until the 2050 deadline to meet the net zero plan. The action plan sets out a set of principles with specific objectives and actions.

i. Placing people at the heart of the future of energy in Northern Ireland. Ensuing people are empowered, supported and protected to enable them to transition to decarbonised solutions for all their energy needs and Households and businesses have access to essential and affordable energy to enable a decent standard of living, health and competitiveness

ii. Grow the green economy. Double the size of the low carbon and renewable energy economy to more than £2 billion turnover by 2030 and for Northern Ireland to become a leading low-carbon innovation hub

iii. Do more with less. Deliver energy savings of 25% from buildings and industry by 2030. Ensure all new buildings are net zero ready by 2026/27 (earlier if practicable). Reduce the distance people travel in private vehicles

iv. Replace Fossil Fuels with Renewable Energy. Meet at least 70% of electricity consumption from a diverse mix of renewable sources. Replace high carbon heating sources with lower and zero carbon sources in households and businesses. support the transition to low and zero carbon fuels for vehicles

v. Create a Flexible, Resilient and Integrated Energy System. Develop markets and infrastructure that integrate low carbon sources and meet energy needs in a secure and cost-effective way. An accessible and digitised energy system where data provides value for consumers and system operation. Decentralised solutions that enable people and communities to be active participants in the energy transition.

Integral to the energy strategy and action plan is the development of an energy evidence programme to aid policymakers in deciding the best course of action to meet targets. This programme should be based upon the best available evidence from a wide range of sources, which includes reviewing existing research, commissioning new research and consulting relevant experts. Within the energy evidence programme a set of priority research areas are outlined, ranging behavioural economics to fuel prices. Of particular importance for this report is the principle of model development mainly the developments of the current Computable General Equilibrium (CGE) model required to replicate the type of energy related applications employed by the Scottish and UK energy CGE models.

In this report we detail the use of CGE models for energy analysis in Scotland and the UK and how the Northern Ireland model could be extended to carry out similar analysis. The report is structured as follows: the next gives a brief introduction into CGE models with a description of the AMOS framework used in Northern Ireland, Scotland and the UK. Following this a literature review of the uses of the AMOS for energy related questions for Scotland and the UK. The second last section outlines some potential uses and extensions of the Northern Ireland AMOS to answer nation specific questions. A conclusion is given in the final section.

CGE modelling Framework

CGE models are one of the most commonly used tools used by policy makers and academics to measure the impacts of changes to a baseline economy. Many conventional economic impact assessments are based on Input-Output (IO) models which use only economic flow data (IO tables) to determine impacts, but these have several limitations and assumptions. CGE models are more advanced and use the combination of IO tables and economic theory to relax several of the assumption of IO models.

The uses of CGE models vary greatly and 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 (but not necessarily) based on neoclassical economic theory, whereby by consumers maximize their utility subject to a budget constraint while producers maximize profit/minimise cost

In IO modelling methods, IO tables were the primary input, but for CGE models the base database is the Social Accounting Matrix (SAM) which is an extension of an IO table incorporating transactions and transfers between institutions related to the distribution of income of the economy (Miller and Blair, Chp 6).

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 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).

In IO models the fundamental assumption is that prices are fixed with impacts solely determined by the demand side. For CGE models this is not the case as relative prices are flexible and supply impacts can be modelled.

CGE is used in the same manner as IO - ex-ante modelling to determine the economy-wide impacts of projects/policy changes. The main differences are that CGE models should be used for larger scale projects/policies which are likely to impact prices and, in any situation, where one may think that the supply side of the economy will have the time to adjust via investment, substitution, etc.

Other than an increase in expenditure some projects/policies may have supply-side changes (such as a change in labour productivity) which also leads to economy-wide impacts. For these types of changes a CGE model should be used as an IO does not allow for these changes to be modelled.

Examples of when to use CGE model include:

- Large scale construction projects
- Increase in labour and/or capital productivity due to a change in policy
- Changes in labour supply
- Increase in Government spending funded by increase in tax
- Changes in capital supply
- Changes in taxation (corporation tax, income tax)
- Changes in tariffs on international tradew

CGE pros and cons

The strengths and weaknesses of CGE models has been widely discussed in the literature (see for example, Greenway et al (1993) and Gilmartin (2010)).

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 models, 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 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 be 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. This, however, can be perceived as somewhat of a weakness, as CGE models are very sensitive to the model configuration 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[3] 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 – such as Cobb-Douglas, Constant Elasticity of Substitution (CES) or Leontief – are used. These functions a relatively restrictive and may not fully represent the production behaviour but they are used to simplify the process of finding a solution. McKitrick (1998) use both to compare the results from using a standard CES and another functional forms with there being noted differences in the results.

3 Whenever possible elasticities estimates for the region being analysed should be used. If these are not available best estimates from the literature are used.

AMOS CGE framework

The Fraser of Allander Institute (FAI) first developed the AMOS (a micro-macro model of Scotland) family on CGE models in 1991 (Harrigan et al (1991) with these being extensively being used throughout academia and government. As previously outlined, these are complicated models requiring a high-level computing power thus there is no single model which can answer every question. Instead in the framework, there is a base AMOS model which is then extended depending on the needs of a project. Department for the Economy (DfE) currently use a version of the base AMOS calibrated to the Northern Ireland Economy. In this section we will outline the features of the base AMOS framework then discuss important extensions for energy and environmental analysis.

Base AMOS is initially calibrated in a steady-state equilibrium, implying that in the base year net migration is zero and investment just covers depreciation. In the absence of an exogenous disturbance the model replicates the base economy across all time-periods, meaning changes in endogenous variables are caused by 'shock'.

As the AMOS framework is based on the national/regional data, the maximum possible number of sectors within the model is based on the IO tables, although for ease of computing these are usually aggregated and the number of sectors usually set to around 30. In addition to the economic sectors/commodities within the model there are three internal institutions – households, firms and governments – and two external, rest of the UK (RUK) and rest of the World. Within the framework the focus region is treated as a small open economy so that RUK and ROW variables are treated as exogenous. Commodity markets are assumed to be competitive. Financial flows are not explicitly modelled, and the interest rate is assumed to be exogenous.

The model can either be run in a myopic (agents have adaptive expectations) or forward-looking (agents have known expectations) specification. There are three core wage closures within the model with varying assumptions on how wages evolve overtime: fixed nominal wage; fixed real wage and wage bargaining, where workers bargaining power is a function of prices and the unemployment rate. Labour supply changes are completely attributed to migration, which is either fixed or determined by the real wage and unemployment rate differential between the region and the rest of the UK.

Fundamentally, the model assumes that producers minimise cost using a nested multilevel production function. The combination of intermediate inputs with RUK and ROW inputs is based on the Armington function (Armington, 1969). Output is produced from a combination of intermediates and value added, where labour and capital combine in a constant elasticity of substitution (CES) function to produce value added, allowing for substitution between these factors in response to relative price changes. Capital stocks are fixed in the short run, but subsequently each sector's capital stock is updated through investment, set as a fraction of the gap between the desired and actual (adjusted for depreciation) level of capital stock.

Energy and/or environmental changes

An extension of the AMOS framework is the AMOSENVI[4] extension, focused on the analysis of energy and/or environmental changes. There are several key distinctions between the base AMOS and AMOSENVI models. First, is the higher level of energy related economic sectors within the model. For example, in Lecca et al (2014) there are 13 energy sectors[5] within the model (nine related to electricity generation) compared with only around four (one electricity) energy related sector in the base model. This does cause some complications though as in the Scottish IO table the full electricity sector covering generation, transmission, distribution and sales is only represented by one single economic sector, which requires disaggregation into the different elements. A range of disaggregation methodologies exist and to simplify the process the AMOSENVI disaggregation is based on the assumption, first outlined in Gay and Proop (1993), that all generation sectors only sell to a transmission sector which then sells to end users[6][7].

The second key distinction in the AMOSENVI models is the use of a different production structure. Output in the base AMOS is a combination of value added (capital and labour) and intermediate inputs. The AMOSENVI output is produced in the same way but the intermediate inputs are separated further using a multi-level CES function. In all sectors, intermediate inputs are decomposed into energy and non-energy inputs, with the energy split into electricity and non-electricity. Non-electricity is further separated into oil and non-oil, with non-oil divided between gas and coal. In the electricity sector, distinction is made between transmission and generation, where the latter is a combination of intermittent and non-intermittent electricity generation[8]. The intermittent sectors are dependent on the disaggregation of the IO tables but are usually marine and wind (separated further into on- and off-shore). Similarly, the non-intermittent composite is commonly split further into low (nuclear, biomass, hydro) and high (coal, gas) carbon generation technologies.

Finally, to enable environmental analysis, the AMOSENVI framework incorporates climate indicators (such as CO2 emissions) into the model[9]. Initially emissions were related to a sectors output, however there we some issues related to this methodology and in recent years there has been a move to relating emissions to sectoral fuel used. Also, as environmental impacts go beyond emissions there has been plans to include other impacts, such as water and material use.

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4 A micro-macro model of Scotland environmental extension.

5 Coal mining; gas mining & distribution; petroleum & nuclear fuel; electricity distribution, electricity coal; electricity gas & oil; electricity nuclear; electricity hydro; electricity biomass; electricity wind; electricity offshore wind; electricity marine/solar; electricity other.

6 If the data is available this assumption can be relaxed with generators selling directly to consumers.

7 Discussed further in the Annex.

8 The separation of intermittent/non-intermittent technologies is a subjective choice made by the researcher. For AMOSENVI the distinction was made that antechnology is intermittent if the output can be varied by manually adjusting fuel inputs.

9 With the AMOSENVI framework the environmental indicators can be updated whenever there is a new SAM is incorporated into the model.

Literature review of FAI modelling using AMOS

Over the past 20 years both the UK and Scottish Governments have placed significant importance on the environment and growing the green economy. With this emphasis the AMOS family of CGE models has been extensively used to analysis potential impacts of planned project/polies in both Scotland and the UK. In this section, we review published academic journal papers in which the AMOS framework has been used for this purpose.

As outlined in the previous section, the core application of CGE models is in standard economic impact analysis, measuring the potential impacts of changes to a baseline economy. With the high level of natural resources, a key component of recent Scottish policy has been to grow the marine (wave and tidal) and offshore wind electricity generation sectors in the Scotland.

Allan et al (2008) use the AMOSENVI extension of the Scottish model to estimate the economic impacts of developing 3 Gigawatts (GW) of marine capacity in Scottish Waters. The focus is on marine energy as, at the time of publication, this was a key sector within the Scottish electricity plan. There are two key motivations for using a CGE model for this study. First, as 3GW of marine capacity would require substantial investment. The authors note that this is a "mega-project", in which the assumption of a passive supply-side in IO models is unlikely to hold. Second, marine energy is a novice technology with the only previous economic analysis related to private costs, whereas this paper investigates the system-wide impacts of deployment. A range of sources are used to incorporate a time dimension into the shock and to separate total expenditure into the Standard Industrial Classification (SIC) sectors within the model. The author's find, as similar with many studies, the increase in expenditure leads to an increase in economic activity.

Marine energy is also the focus of Allan et al (2014), which examines the Scottish-wide impacts of developing 1.6 GW of marine capacity in the Pentland firth and Orkney waters at a cost of £6 billion. Here the authors again use the AMOSENVI version of the model, but the focus is only on the impacts of the temporary construction shocks. Impacts are estimated using an IO model and the CGE under both the myopic and forward-looking specifications. The authors find that the choice of model has significant impact on the economic results, with IO models having larger impacts. This occurs as within IO models the assumption is that there is always enough spare capacity to meet demand, but in CGE this is related with the supply-side specially modelled. Also, legacy impacts (those occurring after the shock) only appear in the CGE as IO economic impacts are only directly related to the size of the demand.

This sentiment that IO models have larger construction cost estimates is also echoed in Gilmartin and Allan (2014) where the authors determine the link between renewable energy capacity and regional economic change with a focus on marine renewables in Scotland. Using the AMOSENVI model and capacity estimated form the Scottish Renewables Forum, the authors find a clear link between regional development and increased renewable capacity. Like Allan et al (2014) only the construction expenditures are modelled within the CGE with the focus on employment, they found employment can play a key role in regional development. The authors find the constructive of renewable capacity leads to positive economic impacts and as with previous studies, there is an overestimation of results using IO and shows the importance of CGE.

Connolly (2020) uses the AMOSENVI to investigate the economic impacts of planned offshore wind capacity in Scotland up to 2022, using both the CGE and IO approaches. They find that the planned offshore wind developments in Scotland will bring considerable economic benefits to Scotland with an increase in output, GVA and employment, However, unlike the previous marine studies (Allan et al (2014); Gilmartin and Allan (2014)), they find that the economic impacts are larger when using the CGE model than that of the IO model. This occurs as the paper analyses both the construction and operational stages of developments. With the IO approach, the operation impacts are solely determined by the scale of the shock. Thus once you reach the operational stage the impacts decrease almost instantly. However, in the CGE with the active supply side during the construction stage, there is also a build-up of labour and capital, changes in prices determining economic impacts, along with demand during the operational stage.

Carbon capture and storage

Turner et al (2021a) look at the economy-wide impacts of carbon capture and storage (CCS) generation in Scotland, using the AMOSENVI model. In the simulations they model the gradual introduction of CCS equipment in the Scottish chemical industry over a 10-year period. The assumption is made that the carbon capture activity requires increased capital inputs to produce a given level of output, resulting in a reduction in capital productivity, combining both a demand and supply side shock. The use of a CGE approach allowed the authors to consider the nature and potential extent of export, GDP and employment losses under three different funding mechanisms. The first is polluters fund the CCS, second is funding achieved through the reallocation of government expenditure and finally funded through an increase in tax.

Linked to CCS, Turner et al (2021b) focusses on the challenges of understanding the likely local and national wider economy impacts of, and the trade-offs involved, in supporting new transport and service infrastructure (i.e., warehouses, pipelines, vehicle fleet) as part of potential CCS systems. They used a version of the AMOSENVI calibrated to UK data (UKENVI), with separated CO2 transported and storage sector, introducing £0.5 billion of investment. Again, by using the CGE it can model different government scenarios, particularly reallocation of expenditure or increase in tax to cover investment.

The research referenced e above have used the CGE in the conventional impact sense, whereby there is a change in demand for specific sectors which causes system-wide impacts. The papers also show that the use of CGE is also important in these studies as they include the supply-side impacts related to labour, prices, etc. CGE models also allow for changes in the supply-side to be modelled.

Emissions

Lecca et al (2017) investigates both the economic and environmental impacts of the cost reduction associated with wind energy in the UK, using a UK calibrated AMOSEVNI. As has been seen in the last rounds of Contract for Difference (CfDs), there has been significant decrease in the cost of generation for offshore wind energy, which would have knock on impacts to the economy. In essence, the cost reductions mean an increase in the electricity generational output (MWh) per capacity (MW) and in the CGE the authors introduce the reduction in wind energy costs as an increase in capital productivity for in the offshore wind sector. In this version of the model, baseline emissions are estimated which are then likely to have sectoral output, meaning changes in CO2 can be modelled at the same time as economic activity.

Energy Efficiency

Generation of energy/electricity is only one part of the green economy. Another large component is energy efficiency and how we use energy. As with generation technologies the AMOS framework has been used extensively to investigate policies and projects.

Hanley et al (2009) use the AMOSENVI model extended with environmental data to argue that a CGE approach is needed to model improvements in energy efficiency. In the paper the authors simulated a broad 5% increase in energy efficiency across the board finding that economic activity increases but so does consumption and emissions. This at first may seem surprising but upon further investigation the authors note that this is caused by lower energy prices increasing substitution, this is known as the rebound effect. This phenomenon would have been difficult to identify without the CGE model.

Several other studies use the AMOS framework to investigate these rebound effects. Lecca et al (2014) use both partial equilibrium and general equilibrium techniques, through the UKENVI model, to measure the rebound impacts of a 5% increase in energy efficiency across UK households. The main contribution of the paper is that they find it possible to find the range of expected rebound effects of an energy efficiency programme using a CGE framework.

A similar study is carried out by Figus et al (2017), in which the authors investigate the system-wide impacts of household energy efficiency improvements in a regional context. Using the AMOSENVI model the authors analyse the impacts of a government funded energy efficiency programme, which provides a 5% increase in overall household energy efficiency in Scotland. With the focus being on regional impacts, two fiscal funding regimes are modelled. First is the 'block-grant regime', where the Scottish Government budget is based on a central government grant and the funding for the energy efficiency comes from a reallocation of budget. In the second fiscal system, the energy efficiency programme is funded by either a reallocation of spending or increase in taxes, with the increase in tax revenue from the resulting system-wide impacts recycled to the Scottish Government budget. System-wide impacts are larger in the second scenario as the energy efficiency programme produces positive impacts on household consumption, increasing tax revenue and thus the Scottish Governments budget.

An extension of the energy efficiency work is found in Figus et al (2017), which again looks at the system-wide impacts of an increase of energy efficiency in the UK using the UKENVI model. Unlike the previous two studies, which only had one aggregate household, Figus et al (2017) considers the impacts on income quintiles by disaggregating households within the model. Like previous studies the use of the CGE allows for different scenarios to be explored. The first is a costless (and exogenously determined) 10% increase in energy efficiency, the second and third are also a 10% energy efficiency increase but government funded by either reallocation of government expenditure or through raising tax. By using a quintile disaggregated version of the AMOS framework, the authors, in addition to economic and environmental, are able to explore the impact of energy efficiency programmes on other government objectives (such as poverty). This is achieved as they able to trace the price changes related to the programmes and how this impacts the fuel costs of the different types of households compared with their income levels.

A key issue for energy efficiency in the UK is how the reduction in industrial and household emissions from heating will be achieved and the associated cost of any retrofitting programme. Katris & Turner (2021) examine the system-wide impacts of enabling and realising energy efficiency programmes in the UK, using the UKENVI with disaggregated household quintiles.

Part of the focus is on the Energy Company Obligation (ECO) programme which is funded through energy bills of all UK households and in turn funds retrofit programmes. This introduces a distributional impact determined by the size of household energy consumption. Two scenarios are investigated with the ECO programme – one with economic rent present and the second no economic rent. A further two retrofit funding programme systems are modelled. The first is a loan to beneficiaries of the programme, with the assumption that efficiency improvements are supported via interest-free loans issued to the households retrofitting their properties, to be paid back within 25 years. The other funding scenario is where the retrofit programme is fully funded through rises in income tax.

In addition to households, a range of papers have investigated energy efficiency and rebound effects within economic sectors. Using the UKENVI model, Allan et al (2007) measure the impact of a 5% improvement, across the board, in the efficiency of energy use in all production sectors. In the model, there are five energy sectors (coal, oil, gas, renewable electricity and non-renewable electricity) with the shock being a one-off permanent step increase in efficiency in each, thus a supply-side disturbance. The results find improvements, in general, across all industrial sectors, in efficiency of energy use in production do have significant rebound effects but no backfire i.e., no increase in energy use. A key component of the paper was the sensitivity analysis of the CGE parameters, with the authors detailing some of the pros and cons of CGE modelling.

Turner et al (2019) investigate, through both a partial and general equilibrium approach, if a technological change could be directed to simultaneously reduce carbon-intensive energy use and deliver a range of economic benefits in the UK electricity sector. The authors introduce a 5% permanent increase in the efficiency to all input into the electricity sector, simulating a technological change. The author's find that an increase in electricity inputs reduces price, with the potential for consumers to switch to electricity from more intensive gas without affecting the macroeconomy.

There has been some debate over the relative short- and long-run rebound effect associated with energy efficiency programmes. In theory, it's predicted that long-run rebound impacts would always be greater than short-run, but this is not always the case in a CGE framework. This is due to the fully flexible response of energy supply prices to shifting demand. Figus et al (2020) use the UKENVI model to explore the effects of energy price stickiness on the evolution of rebound effects. They find that the price stickiness is an important determinant of the time path of rebound effects and of their relative size in the short and long runs.

EV/Transport

In recent years, in the UK, there has been a push towards Electric Vehicles (EVs), demonstrated by the fact that EVs now made up 11.5% (Department for Transport, 2022) of all new car registrations in 2021 (up from 1.7% in 2019). To promote EVs, the UK and regional governments have rolled out several support policies and have committed to upgrade the current electricity system to support EV penetration. Again, the AMOS framework has been used to model demand-side and supply-side simulations, related to these polices and upgrades.

Figus et al (2018) extents the UKENVI framework by separating private transport within the household consumption function into refined fuels and motor vehicles inputs. The purpose of the paper is to model the use of energy intensive consumer services in a more appropriate manner than in the existing literature, using private transportation as an example. The extended model allows for investigation into the wider implications of household vehicle-augmenting efficiency improvements. To model the increase in EV penetration the authors introduce a 10% efficiency increase in the vehicle input of private transportation.

As would be expected with an increase in efficiency, there is an increase in economic activity with some ambiguity around environmental impacts, which need to be invested further.

Alabi et al (2020) use the UKENVI developed in Figus et al (2018) to answer the question whether spending to enable ambitious EV roll-out programmes can in fact generate net gains across the wider economy (i.e., do economic positive impacts of the rollout of EV programme outweigh the negative impacts associated with costs and funding). The authors model two scenarios. First, in isolation, they focus on the impacts from investment spending on the electricity network required to support 20% penetration of EVs in the private transport sector by 2030. To fund the upgrade, the total costs of the project are recovered via electricity bills across a 45-year period. The impacts of the increase in electricity prices outweigh that 'demand' impact of the upgrade investment leading to a slight contraction in economic activity. The second scenario measures the total macroeconomic impact by combing the investment costs from the first scenario with that of a projected 20% EV rolled out (modelled in a similar way to Figus et al (2018)). The key result here is that introducing the EV roll-out, enabled by the network upgrade, generally results in a sustained net positive impact on economic activity.

Alabi et al (2022) is an extension of the previous Alabi et al (2020) work, which instead of investigating the short-term impacts of EV penetration, looks at the longer-term impacts with growth until 2050. In this paper, there are several scenarios related to EV penetration, type of grid upgrade and model configuration. The main outcome of the paper is that the analysis demonstrates that investment in electricity network upgrades to support the EV rollout has the potential to help shift a transitioning economy, like the UK, onto a pathway with higher and better-quality GDP.

Up to now the focus has been on academic papers, which have used the AMOS framework to analyse: the impacts of renewables; energy efficiency and rebound effects and system-wide impacts of EV penetration. Several other papers have used the AMOS for a range of energy related purposes.

Fiscal system

Ferguson et al (2005) summaries' the AMOSNEVI model and argues the frameworks usefulness is as a modelling tool that can inform regional policy making process by identifying the impact of any exogenous policy change on the key endogenous environmental and economic indicators. The paper is not about one specific topic, rather the users simulate several related to the Scottish fiscal system, like increase in government expenditure or income tax rates, and the impact on economic and environmental indicators.

The idea of fiscal policies having system-wide environmental impacts is also explored in McGregor et al (2021). The authors use a regional CGE model (AMOSENVI) to measure the CO2 impact of a balanced-budget increase in public environmental expenditure. A fiscal stimulus, financed through either borrowing or increase in taxes, is modelled which increases long-run GDP by 0.6%. A range of different model configurations are run, and the authors introduce the idea of an environmental social wage, where workers and migrants value higher government spending on environmental improvements equally to their lost consumption expenditure into the model. As with many of the other studies there are a range of results depending on the model configuration, but a double dividend of increased economic activity and reduced emissions is possible.

The details of CGE models, in particular the AMOSENVI framework, are also explored in Lecca, Swales and Turner (2011). Here the authors focus on energy and where exactly this should enter the consumption function, which has been a debate for several years.

A simple demand shock is introduced into the AMOSENVI framework under different assumptions regarding the capital, labour, energy, material (KLEM) production function. Two cases are presented, in the first energy is positioned with the other intermediates input, allowing for substitution between energy and non-energy (or materials) in the intermediate composite input. In the second case, energy enters the value-added nest. Specifically, energy combines with capital, and the resulting composite is then combined with labour (EK + L). The results demonstrate that introducing energy at different points in the KLEM nested production function, does have implications for the stability of results and that modeller judgement, with respect to substitution between different inputs, is important.

Turner et al (2011) use a multi-region version of the AMOS framework (Scotland-RUK) combined with an inter-regional IO table to measure the economic and environmental impacts of trade-flows between the two regions. The authors note that while IO tables are appropriate for conventional pollution accounting, there are some limitations in using the framework to model the response of changes in marginal economic activity, which a strength of CGE models. In the paper, a 10% increase in Scottish manufacturing rest of the world exports are introduced into the CGE model under different wage and migration assumptions. Results from the CGE are then used to generate new interregional IO tables, from which environmental impacts can be estimated.

Cui et al (2016) use the two region AMOS model to investigate two key questions;1) is there tension between delivering on Scotland's regional economic development and environmental targets? And 2) what are the economic and environmental spill over to the other regions of the UK? The authors introduce a permanent 5% increase in labour productivity. The contribution of the paper is not to investigate a specific policy but rather the use of a two-model CGE to calculate changes in both production and consumption emissions. Household and production sector emissions are related to energy use where appropriate and output otherwise. For the consumption-based measure, emissions embodied in imports are estimated using OECD databases.

A carbon tax has been muted as a key policy tool which could be used to reduce emissions. In Allan et al (2014) the authors use the AMOSENVI model to investigate the economic and environmental impacts of a potential carbon tax in Scotland – set at £50 per tonne of CO2. Using the CGE model, they can model three alternative assumptions about the use of the revenues raised from the tax. First, is the taxes raised are not recycled in Scotland (i.e., they go straight to the UK Government). Second, the tax revenues are used to increase Scottish Government expenditure in general, and finally the revenue is used to reduce income tax levels in Scotland. The main finding is that the introduction of a carbon tax would meet the Scottish carbon reduction targets (of 37% by 2021) rapidly and there is the possibility of a double dividend of increased economic activity and reduced emissions, although this is not guaranteed under all revenue assumptions.

Using AMOS for Northern Ireland policy

As outlined in the previous section, the energy system in Northern Ireland is currently going through significant changes which have both environmental and economic impacts. These impacts will be wide ranging and through several discussions with stakeholders we have identified several key areas of interest, which may be explored through the use of the AMOS CGE framework. In this section we discuss the key energy areas for NI identified by stakeholder discussions, with Annex A providing information on the data needs and possible timescales in modelling these areas in a CGE.

The first area would be the standard appraisal investigating the economic impacts arising from investments in the electricity systems, like Scotland and the RUK, NI has the ambition to decarbonise the electricity system, with this being delivered mostly by the combination of wind energy and storage.

With plans to develop a CfD scheme like that of the Great Britain electricity system, the expectation would be that the vast majority of wind energy investment will be private with very little public money needed. In this case, the use of AMOS is straight forward with the analysis being similar to that found in Connolly (2020). First, estimations would be needed on the yearly number of turbines/capacity and associated costs, which are then combined with information (through conversation of developers) on the expected level on 'local content', i.e., the extent to which companies in Northern Ireland will supply components. In some previous uses of AMOS for the appraisal of generation technologies, the electricity sector has been disaggregated to allow for a higher level of sectoral analysis. This would require, due to previous data constraints, the current Northern Ireland AMOS to be updated to the newest year of IO tables then disaggregated using energy generation and pricing data.

Unlike wind energy, electricity storage is likely to require both public and private investment, with any CGE analysis comparable to Alabi et al (2020). First, estimations will be needed on yearly local costs on an energy storage system, in previous studies these have been taken from energy-system/dispatch models. Then, usually through discussion through policy makers, decisions will be needed on the cost of public financing and how this will be funded and incorporated into the model. For this type of analysis, it is most common to either reduce other Government spending to balance the budget or introduce a tax to fund investments. There are different types of tax's (income, consumer, council) which may require some adaption of the NI AMOS to be implemented. Private investment can be modelled like wind energy as an increase in demand for economic sectors. In addition to both wind and electricity storage there will be a need to upgrade the electricity transmission and distribution systems from the public purse. This can be analysed in a similar manner to public energy storage and could include the need for better electrical connections (i.e., cables etc) with other regions which allow for higher import/export capacity.

Electricity is just one element of the energy system which requires investment if NI is to reach its net zero targets, with another element being heat. In the discussions with stakeholders, Geothermal heat was identified as a technology which has the potential to play a key part in the future energy system. Northern Ireland has a large geothermal resource (Palmer et al, 2022) but currently a small industry, which requires significant investment if this resource is to be utilized. As with the electricity technologies discussed above, Geothermal heat could be analysed using the CGE framework, but this would require some updates to the base NI AMOS and inputs from industry and policy makers.

There is no geothermal sector within the base AMOS thus this would need to be developed using information on the industry's structure from experts, If this information is provided then we are able to use the updated model to undertake investment modelling similar to than discussed for the electricity sector.

A key component of the energy system discussed was policy options for biofuels. Biofuels have many purposes in an energy system, ranging from transport to heat, but there is currently not much incentive for these to be produced in Northern Ireland at the levels required to reach net zero. The NI AMOS framework could be used as a tool to aid policymakers in selecting the best possible options to incentive biofuel production (taxes, subsidies, etc). These would impact the environment and economy in different ways, which could be captured in the AMOS framework. Before any modelling, discussions would be needed with policymakers to identify the potential policy options available in NI to promote biofuels. Also, the base NI AMOS model would need to be updated to include base year economic sectoral emissions, as well as a disaggregate biofuels sectors, requiring information in the current makeup of the sectors (i.e., sales and purchases). Similar to the electricity sector, public investment is most likely needed on the biofuel network, thus a similar appraisal to above would also be required to be carried out.

A further discussed key area of interest, which could be investigated in the AMOS framework, is the reduction in Northern Ireland's need for energy imports. In discussion it was mentioned that Northern Ireland, due to the natural resources, has ambitious plans to become completely energy dependant, with all needs met from local sources. CGE models can measure the potential economy and planned impacts of potential projects/policies but not if these are technically achievable. This requires inputs from other models and exports. Thus, before economy-wide impacts could be measured, analysis would need to be carried out on whether such an independent NI energy system was technically feasible, along with associated costs, which are likely to be significant due to the infrastructure needed. The economic analysis would be carried out in two stages. First, a similar analysis to that of the electricity network investment, with emphasis on how the system would be funded, followed by the switch from imports to locally produced energy. Linked was the idea of a stable energy price, with all energy needs met locally. Northern Ireland would then have the potential to fix energy prices (through a CfD scheme or similar) which would impact consumers. With energy used as primary input in many industries, the stable energy prices could have significant economy-wide impacts, which could be measured in the base NI AMOS framework.

Over the past six months there has been significant increases in energy prices, with some households expecting to see a more than double increase in year-on-year gas and electricity bills by October., Due to the linkage between energy prices and the economy, this was seen as another key area which could explored using the NI CGE framework. Energy is a key input into many sectors and final demand actors in the economy and as such increases in prices are likely to have large knock-on economy-wide impacts. A CGE framework is ideal for analysis of these impacts due to economy linkages being incorporated via the IO database and as noted earlier, consumption and supply in the model being driven by price changes. The base AMOS framework could be used to analyse the potential economic impact of energy prices, where the only input needed would be forecasts of expected future prices.

Other than economy-wide impacts, a key aspect in rising energy prices is how these impact different household groups. The changes/fluctuations in energy prices are likely to have a disproportionate negative impact on lower income households as they spend a higher proportion of income on energy (Department for the Economy, 2022b). A CGE model is effective at analysing these types of impacts, as households are treated as separate actors within the model.

The current base NI AMOS has only one household type, so before any additional analysis of energy prices could be carried out this would need to be disaggregated into different household types. Most likely by income quintiles due to data constraints with the Living Costs and Food Survey (LCFS).

Another area which was prominent through the discussions with stakeholders, was incentives for renewables and how effective they are. There are many different types of incentives available to promote renewables with all interacting with the economy in a different way. The NI AMOS framework could be used to analyse different types of incentives giving policy makers insight into the best option for the economy (which may or may not be the best option for other goals, like sustainability). To achieve this would require some update in the NI base model to incorporate the potential funding mechanisms.

While the above areas were discussed as being priority areas for use of the CGE, some others were discussed but would take a bit longer to implement. One of these is the potential to grow energy related industries to attract foreign direct investments. Over the last 150 years Northern Ireland has been known as a manufacturing hub and there are currently many small businesses which operate as part of the green energy supply chain. AMOS could again be used by policy makers to determine the best option for growing the green economy i.e., which industries would bring the largest economy-wide return in investment. For this analysis it would be advantageous to extend the base NI AMOS to include employment skills level by industry to determine the types of jobs which are being created[10]. Finally, there are areas out with those covered in the meetings, which the NI AMOS could be used to explore. These are included in Annex B.

10 Annex B notes some topics which could be applied using the NI AMOS but not discussed in the three meetings with DfE and DAERA officials. These are mostly topics similar to that carried out using the AMOS for Scotland.

Conclusion

In the next 30 years Northern Ireland is expected to become net zero, not only bringing environmental benefits but also the potential to grow the economy. The growth of the economy is uncertain and determined by a variety of factors, most notably the projects to invest and how will these be funded. Because of this the recent Northern Ireland Energy Strategy outlined the evidence programme with the goal of using evidence to inform energy policy decisions and CGE modelling being mentioned as a particularly important tool for this purpose.

This paper has outlined the AMOS framework currently used by the Department for the Economy with a review of the frameworks uses in Scotland and the UK related to energy. We then discuss the frameworks useful for Northern Ireland energy applications, with three keys areas identified: impacts from investment in renewable electricity projects; policy options to increase biofuel production and the system-wide consequences of a fully autonomous electricity system, with all energy needs met within Northern Ireland.

Glossary of Terms

Gross Domestic Product (GDP) - Total monetary or market value of all the finished goods and services produced within a country's borders in a specific time period

Gross Value Added (GVA) – GVA provides a monetary value for the amount of goods and services that have been produced in a country, minus the cost of all inputs and raw materials that are directly attributable to that production. GVA thus adjusts gross domestic product (GDP) by the impact of subsidies and taxes (tariffs) on products.

Endogenous – A variable/parameter in a statistical model that's changed or determined by its relationship with other variables and parameters within the model.

Exogenous – A variable/parameter which is independent of the relations of a statistic model but can still impact endogenous variables.

Myopic – The agents in the model do not have any foresight, they react to changes introduced into the model.

Output – Measurement of total economic activity in the production of new goods and services. Broader definition than GDP as includes the economic activity related to production as well as value of finished goods and services.

Prices Stickiness - Resistance of market price to change quickly, despite shifts in the broad economy suggesting a different price is optimal.

Sector - An area of the economy in which businesses share the same or related business activity, product, or service. Sectors represent a large grouping of companies with similar business activities, such as the extraction of natural resources and agriculture.

Standard Industrial Classification (SIC) – Numerical codes that categorize the industries to which companies belong, while also organizing industries by their business activities.

References

Alabi, O., Turner, K., Figus, G., Katris, A., & Calvillo, C. (2020). Can spending to upgrade electricity networks to support electric vehicles (EVs) roll-outs unlock value in the wider economy? Energy Policy, 138(July 2019), 111117. https://doi.org/10.1016/j.enpol.2019.111117.

Alabi, O., Turner, K., Katris, A., & Calvillo, C. (2022). Can network spending to support the shift to electric vehicles deliver wider economy gains? The role of domestic supply chain, price, and real wage effects. Energy Economics, 106001. https://doi.org/10.1016/j.eneco.2022.106001

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. https://doi.org/10.1016/j.marpol.2013.05.003.

Allan, G. J., Bryden, I., McGregor, P. G., Stallard, T., Swales, J.K., Turner, K., & Wallace, R. (2007). Concurrent and legacy economic and environmental impacts from establishing a marine energy sector in Scotland. Energy Policy, 36(7), 2734–2753. https://doi.org/10.1016/j.enpol.2008.02.020

Allan, G. J., Hanley, N., McGregor, P. G., Swales, J.K., & Turner, K. (2008). The impact of increased energy efficiency in the industrial use of energy: A computable general equlibirum analysis for the United Kingdom.. Energy Economics, 29(4), 779–798. https://doi.org/10.1016/j.eneco.2006.12.006.

Armington, P. (1969). A theory of demand for products distinguished by place of production. IMF Economic Review, 16(1), 159–178. https://doi.org/10.2307/3866403.

Connolly, K. (2020). The regional economic impacts of offshore wind energy developments in Scotland. Renewable Energy, 160, 148–159. https://doi.org/10.1016/j.renene.2020.06.065.

Cui, C. X., Hanley, N., McGregor, P., Swales, J.K., Turner, K., & Yin, Y. P. (2017). Impacts of regional productivity growth, decoupling and pollution leakage. Regional Studies, 51(9), 1324–1335. https://doi.org/10.1080/00343404.2016.1167865.

Department for the Economy. (2022a). Energy in Northern Ireland 2022. Available at: https://www.economy-ni.gov.uk/publications/energy-northern-ireland-2022

Department for the Economy. (2022b). Northern Ireland household energy expenditure: income difference and non-discretionary impacts. Available at: https://www.economy-ni.gov.uk/publications/northern-ireland-household-energy-expenditure-income-differences-and-non-discretionary-impacts.

Department for Transport. (2022). Vehicle licensing statistics data tables; VEH0256 Cars registered for the first time by VED band and carbon dioxide (CO2) emissions: Great Britain and United Kingdom. Available at: https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables.

Emonts-holley, T. (2016). Fiscal Devolution in Scotland: A Multi-Sectoral Analysis. PhD Thesis, University of Strathclyde, 1–436.

Ferguson, L., McGregor, P. G., Swales, J. K., Turner, K. R., & Yin, Y. P. (2005). Incorporating sustainability indicators into a computable general equilibrium model of the Scottish economy. Economic Systems Research, 17(2), 103–140. https://doi.org/10.1080/09535310500114838.

Figus, G., McGregor, P., Swales., J.K, & Turner, K. (2020). Do sticky energy prices impact the time paths of rebound effects associated with energy efficiency actions?. Energy Economics,8, 157–165. https://doi.org/10.1016/j.enpol.2017.09.028.

Figus, G., Lecca, P., McGregor, P., & Turner, K. (2019). Energy efficiency as an instrument of regional development policy? The impact of regional fiscal autonomy. Regional Studies, 53(6), 815–825. https://doi.org/10.1080/00343404.2018.1490012.

Figus, G., Swales, J. K., & Turner, K. (2018). Can Private Vehicle-augmenting Technical Progress Reduce Household and Total Fuel Use? Ecological Economics, 146(May 2017), 136–147. https://doi.org/10.1016/j.ecolecon.2017.10.005.

Figus, G., Turner, K., McGregor, P., & Katris, A. (2017). Making the case for supporting broad energy efficiency programmes: Impacts on household incomes and other economic benefits. Energy Policy, 111(November 2016), 157–165. https://doi.org/10.1016/j.enpol.2017.09.028.

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.

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. (2015). Regional Employment Impacts of Marine Energy in the Scottish Economy: A General Equilibrium Approach. Regional Studies, 49(2), 337–355. https://doi.org/10.1080/00343404.2014.933797.

Greenway, D., Leybourne, S. J., Reed, G. V., & Whalley, J. (1993). Applied General Equilibrium Modelling: Applications, Limitations and Future Development.

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. https://doi.org/10.1016/0264-9993(91)90028-M.

Lecca, P., McGregor, P. G., Swales, J. K., & Turner, K. (2014). The added value from a general equilibrium analysis of increased efficiency in household energy use. Ecological Economics, 100, 51–62. https://doi.org/10.1016/j.ecolecon.2014.01.008.

Lecca, P., McGregor, P. G., Swales, J. K., & Tamba, M. (2017). The Importance of Learning for Achieving the UK's Targets for Offshore Wind. Ecological Economics, 135(2017), 259–268. https://doi.org/10.1016/j.ecolecon.2017.01.021

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. https://doi.org/10.1016/j.econmod.2011.08.014

Northern Ireland Executive. (2021). The path to net zero energy. Available at: https://www.economy-ni.gov.uk/sites/default/files/publications/economy/Energy-Strategy-for-Northern-Ireland-path-to-net-zero.pdf

Northern Ireland Executive. (2022). The path to net zero energy: Action plan 2022. Available at: https://www.economy-ni.gov.uk/sites/default/files/publications/economy/energy-strategy-path-to-net-zero-action-plan.pdf

McGregor, P. G., Ross, A. G., & Swales, J. K. (2021). How fiscal policies affect energy systems: the importance of an 'environmental social wage.' Regional Studies, 55(8), 1354–1364. https://doi.org/10.1080/00343404.2021.1893895.

McIntrye, S. (2012). Regional economic and environmental analysis. PhD Thesis, University of Strathclyde.

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.

Miller, R. E., & Blair, P. D. (2009). Input-Output Analysis. Foundations and Extensions. (Second). Cambridge University Press.

Palmer, M., Ireland, J., Ofterdinger., & Zhang, M. (2022). Net Zero Pathways: Building the Geothermal Energy Sector in Northern Ireland. Available at: https://www.economy-ni.gov.uk/publications/net-zero-pathways-building-geothermal-energy-sector-northern-ireland.

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. https://doi.org/10.1177/016001769802100301.

Shoven, J. B., & Whalley, J. (1992). Applying general equilibrium.

Turner, K., Figus, G., Swales, J. K., Ryan, L., Lecca, P., & McGregor, P. (2019). Can the composition of energy use in an expanding economy be altered by consumers' responses to technological change? Energy Journal, 40(4), 235–253. https://doi.org/10.5547/01956574.40.4.ktur

Turner, K., Gilmartin, M., Mcgregor, P. G., & Swales, J. K. (2012). An integrated IO and CGE approach to analysing changes in environmental trade balances. Papers in Regional Science, 91(1), 161–180. https://doi.org/10.1111/j.1435-5957.2011.00365.

Turner, K., Race, J., Alabi, O., Calvillo, C., Katris, A., Stewart, J., & Swales, J.K. (2021b). Could a new Scottish CO2 transport and storage industry deliver employment multiplier and other wider economy benefits to the UK economy? Local Economy, 36(5), 411–429. https://doi.org/10.1177/02690942211055687.

Turner, K., Race, J., Alabi, O., Katris, A., & Swales, J. K. (2021a). Policy options for funding carbon capture in regional industrial clusters: What are the impacts and trade-offs involved in compensating industry competitiveness loss? Ecological Economics, 184(February), 106978. https://doi.org/10.1016/j.ecolecon.2021.106978.

Annex A - Key areas discussed data requirements

Key area/Policy option	Updates to model required	Data Requirements	Possible project timescales – Inception to full report. In case were there are optional updates/data requirements more than one timescale may be given
Investment in offshore wind	Update model to most recent year of data (optional)	Latest NI IO and SAM database.	6 months
	Disaggregation of the electricity sector in SAM to included separate wind sector (required)	Annual expected offshore wind capacity to come online in NI. Timescale of development for the specific farms (i.e 5/6 years). This can sometimes be found in wind farm Environmental Impacts Assessment reports or through discussions with developers.	
		Expected cost per MW of capacity (CAPEX) being built. Again, there is some generic public information of this available online but for a NI specific model would be best to have discussion with stakeholders/developers. These costs are not static and over time you would expect CAPEX costs to decrease, which we can account for in the modelling. Also need this cost per MW broken down by each stage of development – environmental survey, seabed survey, weather mast, developments (legal, planning etc), turbines, foundations, array cables, export cables, offshore substation, onshore electrical, install & commissioning. If possible, developers could be contacted for this but there is public information.	

		Estimated Operational and maintenance (OPEX) cost per MW/h of annual energy produced. Again, likely to require inputs for NI specific developers. Also, through discussion would need to know if this cost per MWh is expected to increase/decrease over time, and by how much. With the increase in capacity, you would expect OPEX costs per MWh to decrease overtime which should be incorporated into the modelling.	
		Estimated proportion of spend to local NI companies (local content) at each stage of development from planning to OPEX. From experience this is the most difficult to calculate and will require input from NI specific developers. There are UK targets of around 60% local content but there will vary massively for NI as they did for Scotland.	
		Electricity generation statistics on output (MWh) by each type of generation plus information on cost of input fuel and maintenance of different technologies currently operating. These costs don't need to be NI specific as other public information (specifically from BEIS) can be used in the calculations.	
		Estimations on the likely annual reduction in fossil fuel generation output which the new offshore wind replaces.	
Investment in Geothermal	Update model to most recent year of data (optional)	Latest NI IO table and SAM database	9 months
	Incorporate emissions data (optional)	Sectoral emissions by each of the economic sectors in the NI IO/SAM database in the base year. If this information is not readily available estimated emissions can be calculated by using the ONS fuel use by sector database and then scaling for NI using GVA by economic sector.	
	Separation of Geothermal sector in NI SAM (required)	Estimation on the makeup of the current Geothermal sector in NI. What is the industry buying and who is it selling its energy to? This allows the sector to be disaggregated in the NI IO/SAM. Some of this information might be available from the researchers who developed the NI IO tables but will most likely require inputs from stakeholders and experts. The required buying information is what are the inputs the current geothermal sector is using and the industries these are coming from. These inputs include OPEX, labours, etc. Selling is who are the consumers (industries/households) which are using the geothermal energy.	
		Estimations on the planned annual investment in NI Geothermal technology and how much of this will go to NI based industries. Will require inputs from stakeholders.	

Investment in Energy Storage	Update model to most recent year of data (optional)	Latest NI IO table and SAM database.	6 months
	Include tax additional tax variable into government expenditure (required)	Estimate planned annual investment in energy storage.	
		Estimate proportion of annual government and private investment. Would require discussion with stakeholders and industry. Also need how much of this investment is likely to go to NI based companies or to imports.	
		Information how the government plans to pay for investment (tax or reallocation of spending, etc).	
Upgrade of transmission system	Update model to most recent year of data (optional)	Latest NI IO table/SAM	6 months
	Include tax additional tax variable into government expenditure (optional)	Estimated annual local investment in transmissions system and timescales of development.	
		Estimate proportion of government and private investment. Would require discussion with stakeholders.	
		Information how the government plans to pay for investment (tax or reallocation of spending, etc).	
Policy options for Biofuels.	Update model to most recent year of data (optional).	Latest NI IO table/SAM.	6 months
	Incorporate emissions data (optional).	Sectoral Emissions by each of the economic sectors in the NI IO/SAM database in the base year. If this information is not readily available estimated emissions can be calculated by using the ONS fuel use by sector database and then scaling for NI using GVA by economic sector.	
	Include tax additional tax variable into government expenditure (optional).	Information how the government plans to pay for investment (tax or reallocation of spending). What are options for incentives and subsidies available. Need discussions with experts.	
	Disaggregation of IO to include biofuels (required).	Estimation on the makeup of the current Biofuel sector in NI. What is the industry buying and who is it selling it energy to? This allows the sector to be disaggregated in the NI IO table. Some of this information might be available from the researchers who developed the NI IO tables but will most likely require inputs from stakeholders and experts. The required buying information is what are the inputs the current biofuel sector is using and the industries these are coming from. These inputs include OPEX, labour cost, etc. Selling is who are the consumers (industries/households) which are using the biofuel energy.	

Economic impact for being energy independent.	Update model to most recent year of data (optional).	Latest NI IO table/SAM.	1 year
		Assumed annual investment cost in reaching this target and how much of this investment will go to NI business. The data here would be the type of energy investments (i.e offshore wind/biofuel/etc) and the associated costs. Will require information from stakeholders as well as other researchers who work on NI energy supply/demand modelling.	
		Will probably require a range of technologies to become energy independent.	
		Information of current annual energy imports by fuel type (coal, oil, gas, electricity). Estimations on how this is likely to change overtime. Will require discussion with energy systems modellers to gauge how energy investments will change the supply and demand mix. In becoming energy independent it is likely at times there will be large excess capacity. Again, will need discussions with energy systems modellers on how much of this could be exports and how much will be curtailed, which comes at an economic cost.	
Impact of increased energy prices	Update model to most recent year of data (optional)	Latest NI IO table/SAM	6 months for no distributional impacts 9 month including distributional impact 12-15 month if developing NI specific elasticities of demand.
	Disaggregation of households. (Optional but required for analysing distributional impact of changes)	Estimations of future prices of electricity, coal, oil and gas, biofuel, etc. Would require input from stakeholders and other researcher. Because of the unknows here would require a high level of sensitivity analysis. Would also be advantageous to have a NI specific elasticity of demand for electricity but this may not be available. If not available and extension of the project would estimate NI specific elasticities.	
		Access to the micro-level NI Living Cost and Foods Survey. As the NI sample of the LCFS is small will need to pool 3-5 years of data for a better representation of spend. This allows for estimates of the purchase patterns by income quintiles.	
		Other NI specific data source related to spending by quintile might be available but the LCFS is the go to source for previous Scotland and UK quintile separations.	
Design of incentives	Update model to most recent year of data (optional)	Latest NI IO table/SAM	9 months
	Update model to reflect possible policy options (required)	Discussions with government and stakeholders on the possible policy options for energy sector incentives. What are the design of these incentives and how are they expected to funded - developers/suppliers/consumers tax or through other mechanisms. This many require new tax power which NI does not current have access to.	

Annex B – Others potential area that could be investigated

Key area/Policy option	Updates to model required	Data Requirements	Possible timescale
Energy efficiency investment	Update model to most recent year of data (optional)	Latest NI IO table/SAM	6 months
		Annual number of houses requiring retrofit to meet energy efficiency standards and the associated costs of investment. This would require discussions with stakeholders to identify what exactly any planned retrofit programme will include. Much of investment will be to NI based construction companies but would be good to know if there are any costs expected to be imported (both materials and labour).	
EV investment	Update model to most recent year of data (optional)	The estimated annual reduction in energy use from the retrofit programme. This would allow for any 'rebound' effects to be investigated.	6 months
	Update model to reflect possible policy options (required)	Estimation of local annual investment cost of EV infrastructure. Both the level of private and public investment is needed. Thus, discussion is required with stakeholders.	
		Discussion with government on the level on public investment and how this will be paid.	
Analysis of NI carbon tax.	Update model to most recent year of data (optional).	Latest NI IO table/SAM.	1 year

	Disaggregation of energy sector (required).	Electricity generation statistics plus information on cost of input fuel and maintenance of different technologies These costs don't need to be NI specific as other public information (specifically from BEIS) can be used in the calculations	
		Oil is currently a big factor in NI which could be included in any carbon tax. For this a separate oil sector would need to be identified. Currently oil is combined with coal in the NI SAM. Thus, separation would require discussions with statistical team who build the NI SAM	
	Incorporate emissions data (required).	Sectoral Emissions by each of the economic sectors in the IO/SAM database in the base year.	
		If this information is not readily available estimated emissions can be estimated by using the ONS fuel use by sector database and then scaling for NI using GVA by economic sector.	
	Develop extra tax variables (required)	Estimation of level of carbon tax and how the taxable income will be recycled by the government.	
Impact of environmental policies on skills.	Update model to most recent year of data (optional).	Latest NI IO table/SAM.	6 months
	Disaggregated employment within the model into different skill levels (required).	Access to labour surveys for NI. This allows to estimate the qualifications and types of jobs in each economic sector found in the NI SAM.	
Environmental and Economy-wide impacts of NI farming policies.	Update model to most recent year of data (optional).	Latest NI IO table/SAM	6 months
		Discussion with stakeholders on planned farming policy in NI. Will require annual information on local costs and expected timelines. Also, discussions should include what impact these policies will likely have on farming itself. Are they likely to only be taxes etc where the impact is on the demand of products or are they focused on more sustainable farming practices? The latter is more likely to have both demand and supply impacts which CGE models are very useful for modelling.	
Analysis of the links between the NI economy and natural capital	Update model to most recent year of data (optional).	Latest NI IO table/SAM.	1 year
	Introduce natural capital as a separate element in the model. Different types of natural capital can be introduced if/when data is available.	Estimations of the stock and flow values of NI natural capital for the base year of the IO tables. These natural capital accounts have started to be regularly published for the UK as a whole and for some separate regions such as Scotland.	
		Through discussion with experts analyse how natural capital stock evolve over time. This will be determined by the which natural capital is chosen as the focus. For example, land evolves differently to fisheries.	

Annex C – Areas discussed but cannot be analysed in the AMOS framework

Interconnectors and there impacts on security of supply – We discussed the impact of new interconnectors and the impact this would have of NI energy security. While can quantify the economic impact of constructing the interconnectors the CGE is unable to measure the impact these would have on supply. Ideally for this analysis you would use an energy supply-demand model combined with a price model to estimate when exactly the interconnectors would be used for imports/exports and the cost this energy flow.

Electricity and Gas storage and security if supply – Again like interconnectors gas and electricity storage was discussed but the CGE would only be useful for the economic impacts of construction, other models are required to measure the impact on supply.

Agriculture feed source and sustainability feed source – Feed source for agriculture was discussed but the CGE is not equipped to analysis this low-level micro data question.

Circular economy – Some discussion went on around the circular economy and how this will evolve overtime in NI. Currently this is not an area the CGE can be used to investigate. This would require much more data than is currently in the SAM database as well as some key econometric analysis.

Annex D – Disaggregation of electricity sector in IO tables

There has been an argument in the literature for several years than the aggregation of the electricity sector within IO accounts is problematic as it treats the sector which includes generation, transmission, distribution and supply as homogeneous. Because of this there has been many attempts to disaggregate the electricity sector with the most common methods assuming that all generation sells to a distribution sector which then sells to final consumers.

This assumption has been prominent in the literature due to data constraints, but with more data becoming available a full disaggregation where we can determine the links between generators and consumers may be possible. For a full disaggregation for NI we would need the half hourly generation by technology in NI as well as the demand for each sector. This is a new method and would require a detailed research project.

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