STRATHCLYDE

DISCUSSION PAPERS IN ECONOMICS

DEVELOPING AN ELECTRICITY SATELLITE ACCOUNT (EISA): AN APPLICATION TO SCOTLAND, UK

BY
GRANT ALLAN, KEVIN CONNOLLY AND STUART MCINTYRE

NO 19-09

DEPARTMENT OF ECONOMICS
UNIVERSITY OF STRATHCLYDE
GLASGOW

Developing an electricity satellite account (ElSA): an application to Scotland, UK

Grant Allan[1], Kevin Connolly[1]* and Stuart McIntyre[1]

Keywords: electricity, satellite Accounts, ElSA,

JEL: Q22,Q31, Q56

Acknowledgements: This work was supported by the ESPRC under Grant [EP/G037728/1] and EPSRC SUPERGEN Wind Programme under Grant EP/L014106/1.

Abstract

Within the system of national accounts the electricity sector is typically reported as a single entry representing generation, transmission, distribution and trade. The way in which these components interact with the economy differs greatly, a feature lost within the standard accounting framework. In this paper we propose an Electricity Satellite Account (ElSA) approach to better understand the linkages between the economy and the electricity sector, with a particularly focus on generation technologies. To develop this framework, we draw parallels to Tourism Satellite Accounts (TSAs). To illustrate the practical steps in constructing ElSAs, we develop an ElSA for Scotland for 2012. We show how the ELSA framework gives an improved understanding of the electricity sector, which is critical in improving the usefulness of such accounts future climate and energy, as well as economic, policy.

[1] Fraser of Allander Institute and Department of Economics, University of Strathclyde, Glasgow, UK;

* Corresponding author: Sir William Duncan Building, 130 Rottenrow University of Strathclyde, Glasgow, UK, G4 0GE. K.connolly@strath.ac.uk

Introduction

The electricity sector is big business in the United Kingdom (UK), comprising 1.2% of Gross Domestic Product (GDP) in 2017, supporting £11.2 billion of investment, and employing over 85,500 people (BEIS, 2018a). Despite this, national economic accounts contain little detailed information on this important sector. UK national accounts, prepared in line with international conventions for the construction of system of national accounts (SNAs), only report one entry for an aggregate `Electricity: generation transmission, distribution and trade' sector (ONS, 2018). As a result, two aspects are omitted from this conventional 'accounts' view of the electricity industry. First, no economic distinction is made about the range of activities within this sector (e.g. generation, transmission, supply, etc.). Second, there is no way to understand the heterogeneous aspects of the varied generation technologies used to produce the ultimate product of the sector. Given key differences in the role that different generation technologies play in the electricity market, including producing at different volumes and times, for instance, and the quite distinct contributions of transmission and distribution activities from generation activities, the current framework is not useful for understanding the economic value and role of electricity generation.

While it is obvious that different generation methods embody different intensities of employment and greenhouse gas (GHG) emissions, this heterogeneity is lost in national accounts in the construction of an aggregate electricity sector. This really matters as it means that there is no way to understand the relative emissions intensity of each generation type (in terms of GHG/£). Low emission electricity generation at a time when the price of electricity is very low, and thus the economic value of that output is low, is likely to be less economically valuable than low emission generation at times of high demand and consequently high electricity prices and value. It is only by valuing the different elements of generation - which also takes account of the time dimension of both supply and demand - one can begin to understand the progress that is being made in decarbonising the economy.

The coming decades will see significant changes in the electricity sector in the UK, such as the end of coal power generation , the planned closure of significant nuclear generation capacity[2], and the expansion of major new renewable capacity, including offshore wind and solar (BEIS, 2019). These changes are likely to produce a host of impacts not only on the energy system, but also on the economy. The lack of detail available in the economic accounts about

[2] Recently the UK has seen several coal free days

the electricity sector is an impediment to understanding the economic consequences of these major changes. Fortunately, the SNAs have been here before. In 1979 it was recognised that the treatment of the tourism sector in the SNAs was unable to reflect the manner in which that sector contributed to the economy. This necessitated the formulation of a methodology to construct Tourism Satellite Accounts (TSAs) led by the World Tourism Organisation. While the parallels are not perfect - some aspects of TSAs are not relevant or important for the electricity sector - in this paper we explore if it is possible to adapt the structure of TSAs to create a set of Electricity Satellite accounts (ElSAs), and whether this offers a useful framework for analysis.

The contributions of this paper are: first, we set out the parallels between TSAs and our proposed 'Electricity Satellite Accounts' (ElSAs). The ElSA framework permits a focus on the direct economic contribution of the electricity sector to activity in the economy. Second, and the main contribution of this paper, we illustrate the practical steps in the ElSA approach including drawing in data from electricity sector as well as economic sources. We show these steps through the development of an ElSA for Scotland. Once developed out ElSA can determine key aggregates on the Scottish electricity sector in 2012 including: domestic internal electricity expenditure (£1.6 billion), exported expenditure £592 million), and electricity generation GVA of £1.36 billion). To our knowledge, an ElSA has not been developed in the literature to date, and the framework and example outlined here develop a new innovative framework to understand the economic contribution that this sector makes.

The paper proceeds as follows. In Section 2, given their importance in our own ElSA framework, we review the history of the development and use of Tourism Satellite Accounts, and their key elements. Section 3 outlines what the proposed structure of ElSA, discussing the interpretation of each element of the framework and the necessary data. Section 4 presents our implementation of this framework for Scotland in 2012, while Section 5 provides a discussion on the usefulness of the insights gained and Section 6 then describes potential extensions of the ElSA framework. Section 7 concludes and sets out some directions for further refinement of the ElSA method and define future research questions.

Conceptual Satellite Account Framework

The satellite account framework was pioneered through the construction of Tourism Satellite Accounts (TSAs)[3]. Starting in the 1970s, and gaining greater official attention following the

[3] There are other types of satellite accounts, e.g Jones and Lee (2015); Ferreria et al (2018)

recommendations of the WTO General Assembly in New Delhi in 1983, it was at the WTO's International Conference on Travel and Tourism Statistics in Ottawa in 1991 that serious emphasis was placed on constructing TSAs. Since then, through the WTO but also the OECD and EUROSTAT there has been a surge in the creation of internationally comparable TSAs. Key to this was the adoption of a 'recommended methodological framework' in early 2000. The 2008 edition (Eurostat, 2008) is the most recent iteration. Frenchtling (1999) describes TSAs are 'a statistical instrument', that calculates the 'macroeconomic importance of tourism in a certain period of time, usually on a yearly basis', by constructing a set of tables that are consistent with, but provide much more finely detailed information on tourism than, conventional national economic accounts.

There are four key guiding principles to the construction of TSAs. They can be summarised as: 1) basing 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, and; 4) ensuring the internal consistency of all data used and comparability with other macroeconomic data (Eurostat, 2008).

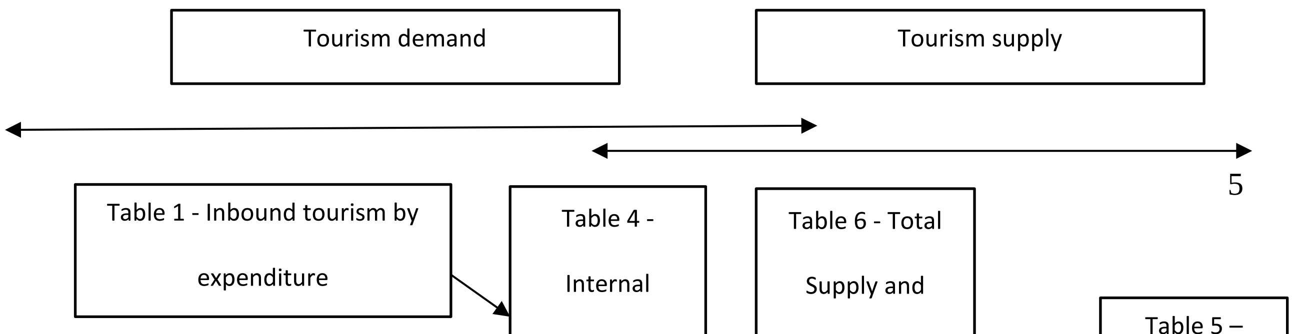
The driving force behind the creation of TSAs was that tourism had specific characteristics which made conventional SNAs ill-suited to capturing tourism activities. The activities of temporary residents are fundamentally different from those of permanent residents, based as they are on a: `...temporary situation in which an individual in the capacity of consumer finds himself/herself: he/she is taking a trip or a visit to a place outside his/her usual environment for less than a year and for a purpose other than being employed by a resident entity there. This differentiates a visitor from the other categories of consumers.' (Eurostat,2008). To treat this type of consumer as if they were a permanent resident, would clearly be inappropriate; although this is what traditional SNAs do.

The fundamental issue with tourism in the national accounts is that there is not a single economic activity which constitutes the production of tourism goods, or an entry which relates to the consumption levels of tourism. Tourism expenditure is defined by the characteristics of goods' consumption (e.g. by a visitor away from their home environment), rather than a specific good. Thus, representing the economic scale of the activities associated with tourism is possible via the detailed provided by the Tourism Satellite Accounts (which are themselves necessarily consistent to the national accounts within which the tourism activity takes place).

TSAs enable the quantification of parallel macroeconomic aggregates to those found in traditional SNAs, but which are based on the unique characteristics of the tourism sector. This means being able to understand the GDP, gross fixed capital formation and employment contribution of this sector, the (hetereogenous) nature of consumption in this sector and its links to the use of domestic and overseas goods and services as inputs (Frechtling. 2010; Song et al, 2012). These satellite accounts are essentially descriptive, reporting on the activities of the tourism sector itself (see for example, Frechtling (1999); Jones and Munday (2010)). Wider economic impacts - such as indirect or induced effects across the rest of the economy - are explicitly not captured in a TSA, however they can be estimated by linking to methods which use economic accounts as a major input, such as Input-Output (IO) or Computable General Equilibrium (CGE) models (Frechtling, 1999). The creation of an ElSA however, can also improve the detail provided within IO and CGE models through providing data to implement a disaggregation of the electricity sector.

A full TSA consists of ten tables, although they can be constructed using as few as seven core tables (Frechtling, 1999). Figure 1 presents a schematic of the seven tables; four on the demand and three on the supply-side. Tables 1-3 capture inbound, domestic and outbound tourism expenditures by product (rows) and type of tourist (columns). Table 4 captures total internal tourism expenditure, adding together elements from Tables 1 and 2. Table 5 provides a representation of the production of tourism activities at basic prices. This is a product (including tourism products, (rows)) by industries (columns) representation. Table 6 is again product–by-industry and focuses on total supply, reconciling domestic supply and total internal tourism demand by linking into the supply and use tables of the SNA, and indicating the share of domestic supply. It is denoted in purchasers' prices. Table 7 links Table 6 to employment in tourism industries (Eurostat, 2008).

Figure 1. Schematic of TSAs framework.



These seven tables provide the core TSA framework. They enable the identification of spending (i.e. consumption) by different types of tourist, making the clear distinction between inbound, outbound and domestic tourists, as well as between day-trippers and other forms of tourist, and the production of the products consumed by tourists in the broader economy. This enables these expenditures to be linked to the jobs that are supported in the economy by this tourism activity. This gives a rounded picture of the scale of tourism in the economy with much greater resolution than one would get from the SNA.

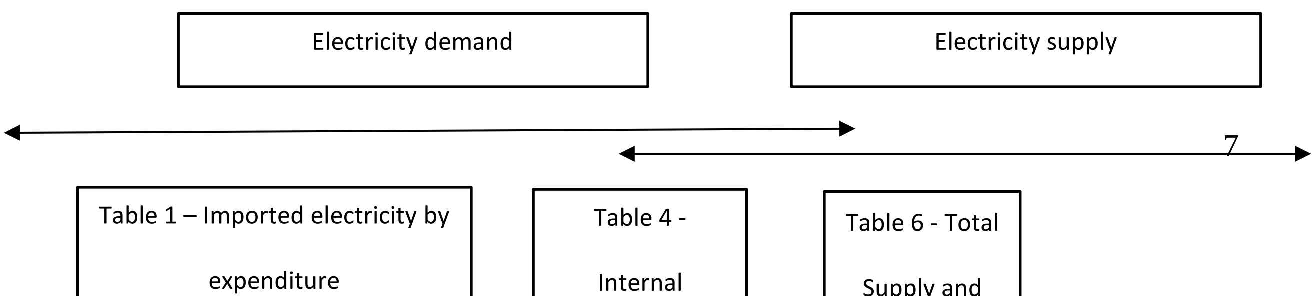
Three additional tables are often included within the TSA. The first (referred to as Table 8) captures the link between tourism and investment, with types of investment spending for tourists (e.g. accommodation for visitors, transport for tourism activities, etc.) in the rows and industries in the columns (showing both tourism and non-tourism industries). The second additional table (Table 9) focuses on non-market services (e.g. public tourism promotion services, visitor information services, etc.) by the level of government that provides this service (e.g. national, regional, local). The final table, Table 10, focuses on non-monetary indicators such as the number of tourists and the number of trips, types of accommodation and transport used in the tourism sector.

Having outlined the structure of a TSA, it is worth listing the key aggregates that are normally reported (Eurostat, 2008) These are: internal tourism expenditure; internal tourism consumption; gross value added of tourism industries; tourism direct gross value added; and tourism direct gross domestic product. These encompass the key elements that, in terms of reporting the economic health of the tourism sector, one would be interested in, but would not know from a traditional SNA. Combined in the TSA, the data permits the user to understand the product and industry nature of tourism consumption, and therefore a framework connecting economic links of tourism to the rest of the economy. Having an additional table linking to employment clearly adds to the knowledge of the activities of the tourism sector. In the next section, we elucidate the rationale and usefulness of applying this framework (appropriately defined) for the electricity industry.

An Electricity Satellite Account (ElSA)

The preceding section summarised a robust - internationally replicable and widely applied - framework for reporting on the activities of the tourism sector in greater detail than otherwise provided from the SNA. In this section we take each element of this framework and explore its adaptation to provide a similarly improved resolution of the activities of the electricity sector in the economy. We begin with a presentation of the overarching framework in Figure 2 paralleling that presented in Figure 1 for the TSAs.

Figure 2. Schematic of ElSA framework.



As before, the first three tables focus on consumption. In this case, we are considering the electricity produced outside, but consumed within, a particular area, i.e. imports (Table 1); domestic consumption of domestically produced electricity (Table 2) and consumption of electricity produced in the 'domestic' location but consumed by those residing outside of that location (so, exports from the area for which the ElSA is being prepared) (Table 3). In the TSA framework, Table 4 gives an overview of the total tourism expenditure in the area, which is a combination of inbound and domestic tourism. In the electricity case, it is the domestic and exported activity which is of most interest to the health of the economy, with imports of less interest (beyond obviously ensuring security of supply, and hence preventing economically damaging outages). Table 4 again aggregates expenditures from Tables 2 and 3. This means that in the ElSA, Table 4 is the combination of Table 2 and Table 3, rather than Table 1 and Table 2 in the TSA[4].

The TSA is concerned with total tourism demand for an economic area, which is the sum of imports of tourism demand (Table 1) and domestic tourist demand (Table 2). In the ElSA case, we are interested in the sum of domestic electricity consumption from domestic generation (Table 2), and domestically produced electricity used outside the area (Table 3). Crucially, in the

[4] 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 outside the area

case of an ElSA, each of these tables can be broken down by generation type as the 'product' with different potential consumer 'types' identified, such as residential, business, etc. Thus in these tables one has an understanding of where electricity is produced, what technology is being used, and who is consuming the electricity. As was noted in the introduction, this is a major advance on what is currently known and reported about the electricity sector in national accounts.

Table 6 in the ElSA is a direct parallel with Table 6 in the TSA. This is the key table bringing together the data from the other tables and reconciling this within the supply and use framework in the SNA. Here the supply of each product, presented in the production account (Table 5), is linked to the sector which uses it, and with total internal consumption of the electricity sector (thus includes imports of electricity). In this way, Table 6 represents total supply and demand of electricity in the domestic economy. Table 7 provides data on employment in electricity generation by technology.

We thus have a framework which tells us: who is consuming what quantity of domestically produced electricity by generation type or `product' (Tables 2 and 3), who is consuming electricity imports by the (non-local) generation type (Table 1), the total domestic electricity consumption by type of generation and consumer (Table 4), the production of each product by each industry in the domestic economy (Table 5), the domestic supply and use of each product in the economy by sector (Table 6), and the level and composition of employment by electricity generation type (Table 7). Doing this enables the calculation of a range of macroeconomic aggregates related to the electricity sector, just as in the TSA.

Having set out the structure of ElSA and explored the parallels between an electricity and a tourism satellite account, in the next section we create an ElSA for Scotland, a region of the United Kingdom, which - crucially for our purposes - is part of a Great Britain-wide electricity grid. The framework that we outline is readily replicable internationally both at national and regional levels, and we develop this in Section 5 later.

Creating and electricity Satellite Account for Scotland

In this section we discuss the implementation of the ElSA approach, but we begin by providing some information about the electricity sector in Scotland.

Electricity in Scotland

In 2016, 44% of total electricity generation (in MWh) in Scotland was from renewable technologies, the remaining non-renewable generation included 42.8% from nuclear, 4.9% from coal[5], 6.8% from gas and 1.5% from oil. Comparing gross generation, with gross 'domestic' (i.e. Scottish) consumption, led the Scottish Government to claim that the equivalent of 54% of gross electricity consumption in Scotland in 2016 came from Scottish (i.e. domestically-located) renewable sources, against its target of the equivalent of 100% of Scottish consumption by 2020 (Scottish Government, 2018).

It is important to note that these 'equivalent' targets do not imply that all Scottish consumption of electricity will be met from domestically-located facilities. In particular, with a Scottish generation mix increasingly producing electricity from variable/intermittent renewable technologies, comparing gross generation and gross consumption ignores the need to match up at each point in time demand and supply. Put differently, there are many times when Scottish consumption is met by imports of electricity from the rest of the UK (and also when Scottish generation is in excess of Scottish demand). Indeed between 2012 and 2017 electrical imports rose by 108%, with exports also rising by 68% in the same period (BEIS, 2018b). This is something that is not explicitly considered in current economic accounts.

The level of imports and exports to and from Scotland will be directly affected by the generation mix in Scotland. For instance, the closure of Longannet, which provided essential baseload capacity, is likely to mean that the number of hours when Scotland is importing electricity - particularly in the absence of replacement generation - may increase. This matching of supply and demand at each time step is central to the construction of ElSA. It will enable us to better understand both the economic value of each unit of electricity generated from each technology, but also to quantify the value of imports and exports of electricity from Scotland.

The creation of an ElSA for Scotland

Tables 1-4

As detailed in Section 3, Tables 1, 2 and 3 denote - in turn - expenditure on electricity produced outside Scotland (imports), domestically-produced electricity consumed in Scotland, and electricity produced in Scotland and consumed by agents outside of Scotland (exports),

[5] The last of Scotland's coal power plants (Longannet) closed in March 2016.

respectively. Examples of these tables are reproduced in reduced form at the end of this paper (in Appendix A). In order to understand the expenditure of different consumer types on electricity produced using different technologies, one must have information on the time path of electricity supply by technology, and electricity demand by consumer type. Our starting point for this is to get information on electricity generation, by generation station, for each half-hourly time-step in 2012 to better understand Scottish electricity supply, before then identifying electricity demand.

The first stage in the ElSA development is to characterise electricity generation (supply) within Scotland by technology for each time step in 2012. For this we use data from the freely downloadable Elexon portal (https://www.elexonportal.co.uk/search). Elexon is a large database containing a wide variety of information relating to the UK electricity network. From the balance mechanism, we are able to estimate the physical electricity generation of each power plant within Scotland at half-hour time periods – the scale at which the UK electricity market operates. This is a key input to Table 2 and Table 3, however for these tables, we also need to know the source of demand for electricity in Scotland.

We can initially think of three broad categories of consumption; domestic (i.e. within Scotland), pumped storage and losses. Domestic use is by far the largest, and includes a number of different types of consumption which one would like to separately identify (for example households, industry and government). Knowing domestic demand at each time step, we can calculate the technology mix at that time step using the Elexon data, and calculate the volume of electricity used by each category of demand, by the technology used to meet that demand, at each time step, summing across all 17,520 time steps in 2012 to arrive at the annual total.

Two other entries in Tables 2 and 4 of the ElSA framework deserve further explanation. These relate to the columns for 'pumped storage' and 'losses'. Quite unlike other forms of generation, pumped hydro both sells to, and purchases electricity from, the transmission network: using electricity principally to pump water back into the reservoir. To understand the profile of its electricity demand (and the generation mix that it 'consumes') we observe when it uses electricity, and calculate the share of electricity use by technology in the same way as we do for other types of consumption group[6].

---

[6] In the Elexon data, for Pumped hydro, positive values indicate that the plant is generating whereas with negative values the plant is consuming electricity from the grid as it pumps water back into the reservoir.

There are two types of losses in the electrical system, 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 resistance losses where electricity will be lost (in the form of heat) due to friction in the cables. Non-technical losses as these are mostly caused by elements which are not related to the transportation or transformation of energy, with the most common non-technical loss being cable theft. As theft, as with non-technical losses, are essentially random there is no way to accurately model their associated losses in the grid. Because of this we combine the technical and non-technical losses from BEIS (2016) to estimate losses at each time step based on the proportion of generation at that time step compared to annual generation.

Finally, in terms of imports and exports of electricity (Table 1 and Table 3), we proceed as follows. Scotland is part of the GB electricity grid with a direct inter-connector with the rest of GB (i.e. England and Wales) and another with Northern Ireland. This is useful, because we have good information on electricity generation in both of these places. In aggregate, over the year, Scotland is a net exporter of electricity. Exports from Scotland to Northern Ireland are known precisely from inter-connector data, and by applying the (Scottish) generation share at each time step to the volume of electricity exported in that time step, we can disaggregate total electricity exported by technology.

Electricity exports to the rest of GB, however, are not directly monitored, therefore we must proceed differently. In our case, given the lack of capacity to store electricity, we assume that Scotland does not import electricity when there is a surplus of Scottish generation (taking into account losses, exports to Northern Ireland and use in pumped storage) over Scottish consumption. Instead, the surplus is assumed to be exported to the rest of GB. This amount can then be broken down further by technology using the Elexon data as before. Conversely, when there is a deficit of generation in Scotland, and demand exceeds Scottish supply taking into account what is happening with the inter-connector with Northern Ireland, this deficit must be made up with imports from the rest of GB. From the Elexon data, we know the generation mix at each time--step in the rest of GB, and therefore can apply those generation mix shares to the volume of imported electricity into Scotland.

In summary, using the Elexon data, we can establish the size and generation mix of domestically used, exported and imported electricity in Scotland. Aggregating the data over the 17,520 time steps in the year produces aggregate data for use in creating Tables 1-3 of the ElSA. Similarly, as detailed earlier, Table 4 of the ElSA follows from a summation of elements in Table 2 and Table 3.

We outlined earlier that in the Elexon data one finds electricity disaggregated according to three categories of demand: 'domestic', 'pumped storage' and 'losses'. In order to better understand what is happening in the electricity sector and to link to the economic accounts (for households and different sectors of the economy), one needs to be able to further disaggregate the 'domestic' category. In this section we describe our approach to this challenge. We start by noting that Scottish half-hourly electricity demand is not directly reported, but can be indirectly inferred from information reported within Elexon. Elexon provides data on half-hourly electricity demand for the GB grid along with the England & Wales grid. In this work, Scottish demand is assumed to be the residual of GB demand minus England & Wales demand at each time step.

In order to split this estimated aggregate electricity demand into the demands from each type or sector of consumption, there are different approaches that one could take. Some authors (e.g. Filik et al (2009)) use short/long term forecasting models based on linear regression techniques to temporally disaggregate the electricity demand data. Similar approaches have been used for forecasting electricity prices (e.g. Skantze et al (2000)). Other papers disaggregate overall electricity demand into final use through the use of normalised demand profiles (Farinaccio et al (1999), Hesmondhalgh (2012)). The use of normalised demand profiles is the method applied to in this paper.

Our first step is to disaggregate these consumption data by time-step according to whether the electricity is being used by households or firms. To do this, we use demand profiles produced by Ofgem (2012) and Elexon. These detail the normalised electricity use by half-hour for different consumers, and are created using one of two main approaches. The first is based on measurement of electricity use over a significant period of time (e.g. as done by Reichmuth (2008)). The second is using software (Clark et al, 2011) to model electricity demand use for different buildings.

The domestic and industrial profiles used for this paper are from Elexon and we have 10 profiles for the services sectors[7] identifiable from Ofgem (2012). First we must calculate the overall yearly demand for each of these sectors with demand profiles. The Energy in Scotland (2016) publication splits overall Scottish electricity consumption into three sectors: households, industrial and services for which we separate further using BEIS (2016) information[8] .

---

[7] These are: offices, communication, education, government, health, hotel, other, retail, sport and warehouse.

[8] The assumption made is that the Scottish services sector consumption proportions are the same as the UK as a whole.

Using the normalised demand profiles, we 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. We then applied a set of seasonal profiles to these weekly profiles, thus week to week these profiles 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). We account for variation in electricity demand by introducing a variation constant[9].

$$Variation\ Constant\ (t)\ _i = \frac{Scottish\ demand\ (t)_i}{Average\ demand_i\ (Season)}$$

$$new\ normalised\ output_i = old\ normalised\ output_i * variation\ constant\ _i$$

Appling the normalised constants for each half-hourly interval to each of the sector profiles gives 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 using:

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

Tables 5-7

Table 5 of the ElSA framework, like Table 5 of TSAs, is a production account. The rows of this production account are the products produced by each industry and, in the columns, each of the industries in the economy. For the creation of this table information from ElSA table 2 and a Scottish Domestic Use[10] table was used.

In the SNA framework for Scotland there is a Products-by-Industry Combined Use (Domestic Use and imports) table provided, however there is no publically available Domestic Use table. As our focus on a production account is with regards to Scotland only we need a way

[9] The assumption being made here is that sectoral demand varies in the same proportion as overall Scottish demand.

[10] The Domestic Use is from the SNA accounts provided by Scottish Government

to develop the domestic use table. Information was obtained from the Scottish Government (Scottish Government, 2017) which allowed product by industry imports to be found as well as other information which aids in the creation of the Domestic Use table.

The information from the Domestic Use table is then used in the creation of a production account by using a method similar to that found for Table 5 of TSAs (Eurostat, 2008). For all products other than electricity, the rows - showing the sales of each Product by each Industry - use the exact information from the rows found in the Domestic Use table. In the production account, the electricity products rows have to be separated by generation products (coal, wind etc) which will leave a residual electricity non-generation product which represents wholesale and retail trade in electricity, transmission, sales etc. The electricity products rows are filled with information from Table 2 with regards to domestically used electricity for each of the industries, with the electricity industry being generators own-use. With the products rows accounted for information has to be included which represents gross value added. As this is not included in the domestic table it comes from the Scottish Industry-by-Industry (IxI) tables (Scottish Government, 2018b).

Table 6 uses the data in Table 5, but extends it by incorporating exported products from Table 3 to fully characterize domestic supply of product. In addition we report the value of taxes less subsidies on those electricity generation products, using information from the ROC[11] register[12].

Results and Discussion of the Scottish ElSA

The previous section outlined the approach taken to develop an ElSA for Scotland in 2012. The primary purpose of the development of an ElSA is to improve the analysis of the electricity sector within the SNA framework, similar to a TSA for tourism. In this section we demonstrate the

[11] The Renewable Obligation Certificate Scheme (ROCs) was introduced in 2002 with the goal of increasing the proportion of renewable electricity on the network in the UK. Under this scheme electricity suppliers must prove that a certain amount of electricity (based on targets) has been generated through renewables source, achieved through the purchase of ROCs (at the set buyout price) from accredited generators (Grimwood and Ares, 2016).

[12] For more information see:https://renewablesandchp.ofgem.gov.uk/

construction of an ElSA, using the example of the Scottish electricity system, to demonstrate the usefulness of the ElSA approach[13]. Table 1 below gives the value of imports of electricity.

Table 1. Aggregated Table 1 of Scottish ElSA.

[13]Full tables can be found in Appendix A

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

Table 1 shows that imported electricity to Scotland in 2012 was dominated by conventional power, plants, which would be expected. Penetration levels of renewable technologies is much higher in Scotland than the UK as a whole, thus Scotland needs to imports when these are not available but non-renewable power is. We can immediately see the usefulness of the ElSA framework as we can identify the imported electricity by product, in the same way as Table 1 of the TSA identifies inbound tourism by product.

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

Table 2. Aggregated Table 2 of Scottish 2012 ElSA.

	Domestic use electricity expenditure (£m)			
	Households	..	Losses	Total

Products				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

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 in England there are 6 nuclear power stations (6.6MW capacity) for a population of 54 million. We estimate that 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, in 2012 there were two large coal fired power station operating in Scotland.

Within the standard SNA framework this information on the electrical consumption (by sector and value) is not available. Table 2 of the ElSA framework allows use to find the expenditures on electricity generation by technology and where it is being used.

Table 3. 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

One of the most interesting figures when comparing Tables 2 and 3 of the Scottish ElSA is the expenditure of domestically used (£240 million) and exported (£120 million) wind energy 33% of the total expenditure on wind comes from selling it to rUK from exports. A fact that is not shown in the standard SNA framework.

This is 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 electricity that consumers in Scotland can useat any time the connections to Northern Ireland and England enables this electricity to be exported.

As Table 4 is a combination of Tables 2 and 3 there is no need to include it in the main body of this text however below is presented is Table 6 which combines the information from Tables 4 and 5.

Table 4. 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	0	412.02	117.8	48.3%
Gas	111.9	66.3	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					

This table contains information on both the demand side and supply of the electricity generator sector. 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 in 2012 was £2.2 billion (Table 4); and electricity generation GVA was £1.36 billion (Table 5).

Other than the core tables, the development of the Scottish ElSA allows for other variables, otherwise excluded from the SNA framework, to be investigated. 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 can be easily calculated. 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 time-step gives the total yearly expenditure, at market price, for a technology, which is then divided by the total generation by technology to give the average price of electricity.

This average price of electricity allows for investigation into the different principle of operation of the two different generation plants. Table 4 displays these average price of generated electricity over the year.

Table 5. Average price electricity by technology.

Products	Average price (£/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

The highest average 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 it produces at times when the electricity price is the highest. Coal and gas power plants have similar average prices of electricity, not surprisingly since they both have similar operation principles as they both can vary output to meet demand.

From the above set of tables we can see the usefulness of using a satellite account approach for the electricity sector, which gives a higher level of detail not found within the SNA framework. We will outline some further detail in the next section. Conceptually and practically we have outlined the building of the first known electricity satellite account with the hope being that this paper can be used for other regions/nations to develop their own ElSAs..

Extension of ElSA framework

In this paper the methodology to create an electricity satellite account to extend the analysis of the electricity sector within the SNA frameworks has been outlined. However, rather than solely being an accounting framework there of several uses/extensions.

Identified in Section 2, IO and CGE models are commonly used to measure the macroeconomic impacts resulting from policy change. There is a large literature on these model used to identify energy-economy-environment interactions (e.g Cruz 2002; Lui, 2012). In the literature IO/CGE models are calibrated using national/regional input-output tables, an integral part of the SNA framework which typically have a single electricity sector. These standard models, due to their aggregation of generation (by types) and non-generation activities into a single electricity sector, are ill-equipped for energy-economy-environmental analysis. Several authors have set out to disaggregate the electricity sector in generation and non-generation sectors (e.g. Gay and Proops (1993); Allan (2007); Weidman (2011)). These sectors use two basic principles in their disaggregation – all sales for generation are to the non-generation sector and generation is separated out using their shares in overall annual generation by generation mix.

Table 5 of the Scottish ElSA demonstrates that different principles of operation means there is variation in the average price of electricity for each generation technology. However, with using generation mix to separate electricity sales, this previous literature is making the assumption that the average price of electricity is the same for each technology. A clear use of the ElSA framework set out in this paper = is to use the total value of generation sales by technology in the disaggregation of the electricity sector with IO tables. This would relax a

In the development of the Scottish ElSA we use a large quantity of data related to the electricity system such as: generation, demand, imports. We use ElSA to measure the economic value of the generation system in 2012. However, in energy policy, there are other principles of the energy quadrilemma (specifically, energy security, environmental sustainability, and cost of energy) which could be investigated using this same data. One future extension of the Scottish ElSA would be to development an electrical supply-demand model, simulating changes in generation to measure the impact on imports/exports. This gives an indication at which times Scotland would be relying on other regions of the UK and also when there is a large amount of exports from Scotland.

Conclusion

The electricity sector, due to its size and nature is a key sector in all economies. However, it is not well represented, within the internally recognised SNA framework. Instead generation transmission and distribution are aggregated into a single sector. 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, this paper has developed an Electricity Satellite Account (ElSA) framework, and then demonstrated in application using Scottish data for 2012. To the author's knowledge, this is the first attempt at the development of an ElSA – both conceptually and practically. 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.

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 and adapt the principles 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.

This full account gives a better understanding of the electricity sector than otherwise found within the SNA framework. In the first four tables we find the expenditure of imports, domestic use, exported and generated electricity, which are lost in the highly-aggregated SNA framework. Also Table 5-7 provide information on the supply of electricity which is otherwise unknown. 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).

In addition, while the ElSA framework allow for an improved understanding of the electricity sector within the SNA, these new accounts can also be used for other purposes. 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 in turn can feed through to economic models such as Input-Output (IO) Computable General Equilibrium (CGE) to address the major questions of policy which require detailed understanding of the relationship between generation technologies and the wider economy (Linder et al, 2013). One such policy relevant question which could possibility investigated a electricity disaggregated economic model would be a carbon tax, where impact will be different across electricity generation technologies. A carbon tax has varying impacts depending on technology, a detailed electricity IO table would allow the modelling to track the impacts across technology.

References

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, 243–254

BEIS. (2016). Electricity generation and supply figures for Scotland, Wales , Northern Ireland and England , 2012 to 2015.

BEIS. (2018a). UK Energy in Brief 2018,

BEIS. (2018b). Energy Trends Electricity: Electricity generation, trade and consumption.

BEIS. (2019). UK Offshore Wind Sector Deal

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, 227–247.

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.

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, 245–259.

Eurostat. (2008). 2008 Tourism Satellite Account : Recommended Methodological Framework (TSA : RMF 2008), Statistical Commission (Vol. 39)

Ferreira, J-P. Ramons, P., Cruz, L. and Barata, E. (2018). The opportunity costs of commuting: the value of a commuting satellite account framework with an example from Lisbon Metropolitan Area, Economic Systems Research, 30, 105-119;

Filik, U. B., Gerek, O. N., & Kurban, M. (2009). Hourly Forecasting of Long Term Electric Energy Demand Using a Novel Modeling Approach, Innovative Computing, Information and Control (ICICIC), 2009 Fourth International Conference On, 115–118.

Frechtling, D. C. (1999). The toursim satellite account foundations, progress and issues. Toruism Management, 20, 163–170.

Frechtling, D. C. (2010). The toruism satellite account: A Primer. Annals of Tourism Research, 37, 136–153.

Gay, P. W., & Proops, J. L. R. (1993). Carbondioxide production by the UK economy: An input-output assessment. Applied Energy, 44, 113–130.

Garton Grimwood, G., & Ares, E. (2016). Energy : The Renewables Obligation. House of Commons Briefing Paper, (05870), 1–10.

Hesmondhalgh, S. (2012). GB Electricity Demand – Initial Brattle Electricity Demand-Side Model. GB Electricity Demand Project.

Jones, C., & Li, S. (2015). Tourism satellite accounts for regions? a review of development issues and an alternative. Economic Systems Research, 22, 117-133

Jones, C., & Munday, M. (2010). Tourism satellite accounts for regions? a review of development issues and an alternative. Annals of Tourism research, 52, 341–358.

Lindner, S., Legault, J. and Guan, D. (2013). Disaggregating the electricity sector of China's input output table for improved environmental life-cycle assessment", Economic Systems Research, 25, 300-320.

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, 123–141

Ofgem. (2012). Demand side response in the non-domestic sector.

ONS. (2018). UK input-output analytical table.

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, 757–761.

Scottish Government. (2017). Personal correspondence.

Scottish Government. (2018). Energy In Scotland 2018.

Scottish Government (2019) Symmetric Input-Output tables.

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, 2–61.

Song, H., Dwyer, L., Li, G., & Cao, Z. (2012). Tourism economics research: A review and assessment. Annals of Tourism Research, 39, 1653–1682.

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, 5900–5907.