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INCORPORATING CO_2 EMISSIONS INTO MACROECONOMIC MODELS THROUGH PRIMARY ENERGY USE

BY

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Incorporating CO2 emissions into macroeconomic models through primary energy use

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Abstract

Two key pillars of the energy quadrilemma (which measure the sustainability of energy policy) are a reduction in greenhouse gas emissions and economic development. Recent worldwide energy policy has focused on the reduction of greenhouse gas emissions to combat climate change, which will influence, and in turn be influenced by, economic activity and energy use. As such, it is of critically important to identify and incorporate emissions into macroeconomic models. Typically, emissions are linked to economic activity via the level of output, both calculated at a sectoral level. However, this approach – while consistent with linear models such as Input-Output - assumes that emissions per unit of output remains constant, which can be problematic with more complex economic systems. In this paper we detail a method for incorporating sectoral and aggregate CO_2 emissions into a macroeconomic model (CGE) of the UK through the use of sectoral primary energy use.

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Key words: Emissions, Macroeconomic models, Primary Use Energy

JEL: Q43, F64, O13

1. Introduction to Energy Policy and Emissions

The reduction of greenhouse gas emissions is a key element of international energy and environmental policy, with there being a move towards 'greener' policy, such as through the Paris Agreement. While there are many greenhouse gases (e.g. Carbon Dioxide, Methane, Nitrous Dioxide) much of the focus of current policy, however, is on the reduction of emissions of carbon dioxide. This is the main driver behind man-made global warming, and is the key pollutant arising from fossil fuel energy production, which has increased dramatically since industrialization.

Both the UK and Scottish Governments have made commitments to reducing CO_2 emissions. The UK Government's Climate Change Act set the carbon dioxide reduction target to 34% compared with 1990 levels and 15% of energy from renewables by 2020. While Scotland carbon reduction is set at 42% by 2020. For the longer term, the UK Government has set the a target from 80% greenhouse carbon reduction (from 1990 levels) by 2050 while the Scottish Government has set a 90% target in the same time period (Scottish Government, 2018)

With the reduction of greenhouse gas emissions being of the upmost importance in energy policy it is crucial for these emissions to be measured and reported accurately so that progress towards targets can be monitored. There are several methods in which greenhouse gas/CO_2 emissions can be reported and linked to sectors of the economy. In this section, we give a brief overview of methods available. In the next section, we outline our extensions to current work using primary energy inputs for use in computable general equilibrium (CGE) modelling of the UK economy.

The UK Government reports on greenhouse gas emissions using three different approaches (ONS, 2018): the UK greenhouse gas inventory from DECC, UK Environmental Accounts from ONS and embedded emissions from DEFRA. While these approaches all measure greenhouse gas emissions, their methodologies and boundaries differ.

The greenhouse gas inventory[1] has measured and reported on greenhouse emissions since 1988 and is on a territorial basis, i.e. only emissions occurring within UK boundaries are reported. This is the basis on which progress in meeting agreements and emissions reduction targets are assessed. A series of emissions factors and models (including fuel use) are used to determine emissions by source. Notably, unlike the UK Environmental Accounts the UK greenhouse gas inventory does not record emissions at Standard Industrial Classification (SIC) code level, representing the structural detail of economic activity.

[1] http://naei.beis.gov.uk/

In the UK Environmental Accounts[2] emissions are reported on a resident basis rather than a territorial basis meaning than emissions by UK residents and registered companies in other countries are included but emissions from foreign nationals and businesses are not. For this approach, a wide variety of data sources (including the greenhouse gas inventory) and models – especially transport – are used. Table 1 summaries the GHG results for 2010 using each of the three detailed methodologies.

Table 1: GHG emissions summary, in MKG CO_2e

Territorial (Greenhouse Gas inventory)	597,051
Resident (ONS)	687,185
Embedded	727,906

None of the two above approaches account for the emissions of goods and services outside the UK that are created in the production of items destined for consumption in the UK. The final of the UK Government approaches, embedded emissions, reports of these emissions known as consumption based[3]. These embedded emissions are calculated using a multi-region input-output (MRIO) model, to link the flows of goods and services described in monetary terms, with the emissions generated in the process of production (DEFRA, 2018).

2. Economic modelling and CO_2 emissions

The purpose of this paper is to detail a method to incorporate emissions at sectoral level relating to energy use. These can then be used in an economic model of the UK, and so to generate economic and emissions results consistent with economic disturbances. A common method used in determining changes in emissions resulting from a change in the economy is to use greenhouse gas emissions intensity coefficients (e.g Pascual-Gonzalez et al, 2016). These coefficients give the CO_2 (greenhouse gas) emissions per £ of sectoral output. Using a standard multi-sectoral modelling framework, such as Input-Output (IO), variations in sectoral output resulting from a change in the economy relative to the base year can be determined. This can then be combined with the emissions intensities to give the implied changes in emissions by sector[4]. While this method is a widely used there is a fundamental problem with the assumption that emissions intensities are unchanged. In an IO context this is consistent with the assumption of fixed relative prices, implying no substitution in production between

[2] https://www.ons.gov.uk/economy/environmentalaccounts
[3] https://www.gov.uk/government/statistics/uks-carbon-footprint
[4] This is consistent with the treatment of, e.g. employment, in IO models.

input to each sector and so a linear response between sectoral output and input use, including of energy products.

It is likely that if there are changes in the economy there will be changes in the CO_2 intensities due to different process/fuels used. With this being the case, other methods are required to link CO_2 emissions with changes in the economy. The method detailed in this note is based on sectoral primary fuel use.

3. Method (UK)

ONS (2017)[1] contains information on sectoral physical use of 19 different types of fuel in MTOE (Millions of tonnes of oil equivalent). As the UK IO table only recognises three fuel types the first step is to aggregate these 19 fuel types. Table 2 below records our classification of these fuels.

Table 2: Classification of fuels

Coal	Coal, Coke, Petroleum Coke, SSF.
Oil	Aviation fuel, Aviation turbine fuel, Burning oil, DERV, Fuel Oil, Gas Oil, Naphtha, Petrol, Waste Oils.
Gas	Blast furnace gas, coke oven gas, colliery methane, LPG, Naphtha gas, OPG.

With the focus being emissions, this physical use of energy was converted to CO_2 using the UK emissions factors (UK Government, 2010). As we have categorised each of the 19 fuel types, for this method we calculate a proportioned emission factor for each of the 3 primary fuels (coal, oil and gas) for each sector by equation 1:

$$Newfactor_{ij} = \frac{\sum(Emissionsfactor_{kj} * fueluse_{kj})}{\sum fueluse_{ij}} \quad (1)$$

where *i* being the aggregated fuel type, *j* economic sector and *k* the ONS (2017) fuel types of *i*.

Using these emissions factors, sectoral base year emissions are:

$$Emission_j = (fueluse_{coalj} * newfactor_{coalj}) + (fueluse_{oilj} * newfactor_{oilj}) + (fueluse_{gasj} * newfactor_{gasj}) \quad (2)$$

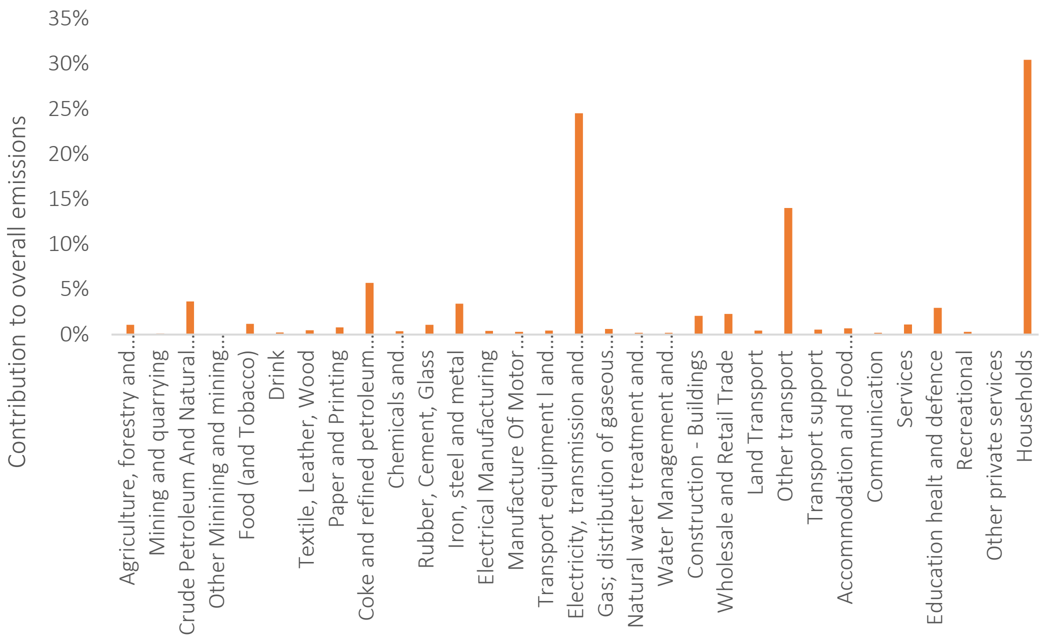
4. Results

As detailed in the previously, there are several approaches the UK Government use to reports on greenhouse gas/CO_2 emissions. In this section, we compare the results from our method with these of the UK territorial and resident based reports for 2010 (ONS, 2017). As the UK territorial database is not detailed at SIC code it is difficult to match directly with the sectoral emissions incorporated into the CGE model.

However, using our primary fuel use method (which contains territorial emissions) we estimate the overall UK GHG emissions to be 604,343 MKG CO_2e, which compares favourably with the UK greenhouse gas inventory of 597,051 MKG CO_2e. One source (sector) we can report on emissions in both method is energy supply where our primary use method estimated GHG emissions to be 208,877MKG CO_2e compared with the reported figure of 207,222 – a difference of 0.8%.

Figure 1 presents the contribution of each sector to total emissions[5]. An example of these calculations for a single sector are given in Appendix A. As expected, there are 3 sectors which dominate territorial GHG emissions: Households (which includes travel) accounts for 30.47% of GHG, energy supply 34.69% and other transport 15.02%.

Figure 1: Sectoral contribution to GHG emissions



[5] For computational purposes there is a higher level of sectoral aggregation in CGE models.

We note earlier that there are a several methods in which emissions are measured within the UK. In this result section, we only compare the results of our primary use method with UK territorial as this is the most closely related. Both the resident based and embedded methodologies include emissions out with UK boundaries thus there is no information on primary fuel use. Appendix B gives a summary of the calculated sectoral emissions in MKG CO2e for the UK for 2010.

5. Using emissions in an CGE model

We outlined a method for incorporating baseline GHG emissions, based on primary energy use in previous sections. To determine emissions resulting for changes in the economy, simulations are run using the CGE model, which give the sectoral changes in the use of each of the primary fuels. With these changes, we can then calculate the new emissions by.

$$Newemission_{ij} = emission_{ij} * \Delta use_{ij} \quad (3)$$

Δuse is from the CGE modelling. The change in total emissions is calculated as:

$$\Delta emission = \sum Newemission_{ij} - \sum Emission_{i} \quad (4)$$

6. Summary

In the last 20 years energy policy started to focus on tackling climate change through the reduction of greenhouse gas emissions – in particular CO_2. With this focus on climate change there is a clear need in having greenhouse gas emissions changes incorporated into economic models. This would allow for changes in emissions resulting from e.g. economic policy to be determined. A method commonly used for this purpose is the use of CO_2 output coefficients. However, these are problematic as the assumption is made the coefficients are constant even in the presence of economic changes. In this paper, we outline a method for incorporating greenhouse gas emissions into a CGE model based on sectoral primary fuel use for the UK. Our results closely match published UK totals for territorial CO_2 emissions, while giving a degree of sectoral disaggregation. This permits these our estimates to be used within multi-sectoral models for the UK. Primary energy use is responsible for most GHG emissions, but there other contributors (such as animals in agriculture) which will be the focus of future work.

Appendix A – Example calculation

This appendix gives an example calculation of the emissions using primary fuel inputs for incorporating into economic models. This example is for the calculation of CO_2 emissions in one economic sector (communication services) in 2010.

List of Abbreviations:

- Communication Services – CS
- Aviation Spirit – AS
- Aviation Turbine Fuel – ATF
- Burning Oil – BO
- Diesel Road Fuel – DERV
- Fuel Oil - FO
- Gas Oil – GO
- Naphtha – NAP
- Petrol - PET
- Waste Oil - WO

$$Newfactor_{gas,CS} = \frac{\begin{matrix}(EF_{AS.CS}*FUS_{AS,GS})+(EF_{ATF.CS}*FUS_{ATF,GS})+(EF_{BO.CS}*FUS_{BO,GS})+(EF_{DERVCS}*FUS_{DERV,GS}) \\ +(EF_{FO.CS}*FUS_{FO,GS})+(EF_{GO.CS}*FUS_{GO,GS})+(EF_{NAP.CS}*FUS_{NAP,GS})+(EF_{PET.CS}*FUS_{PET,GS}) \\ +(EF_{WO.CS}*FUS_{WO,GS})\end{matrix}}{FUS_{AS}+FUS_{ATF}+FUS_{BO}+FUS_{DERV}+FUS_{FO}+FUS_{GO}+FUS_{NAP}+FUS_{PET}+FUS_{WO}}$$

(A1.1)

With *i* being the aggregated fuel type, *j* economic sector and *k* the ONS (2017) fuel types of *i*.

$$Newfactor_{gas,CS} = \frac{\begin{matrix}(3{,}128*0)+(3{,}150*0)+(3{,}150*0.) \\ +(3{,}073*0.07)+(3{,}216*0)+(3{,}190*0.01) \\ +(3{,}131*0)+(3{,}135*0.02)+(3{,}171*0.0)\end{matrix}}{0.07+0.01+0.02} \quad \text{(A1.2)}$$

$$Newfactor_{gas,CS} = 3097 \text{ MKG per MTOE}^{6} \quad \text{(A1.3)}$$

$$Emission_{CS} = (FUS_{coalCS} * newfactor_{coalCS}) + (FUS_{oil,cs} * newfactor_{oil,CS}) + (FUS_{gas,CS} * newfactor_{gas,CS}) \quad \text{(A2.1)}$$

$$Emission_{CS} = (0 * 0) + (2809 * 0.04) + (3097 * 0.1) \quad \text{(A2.1)}$$

$$Emission_{CS} = 422.1\text{MKG} \quad \text{(A2.3)}$$

[6] MTOE = Mega (10^6) Tonne Equivalent

Appendix B – Calculated calculation

Table B.1: Sectoral Emissions in MKG CO_2e, for 2010, UK.

1. Agriculture, forestry and fishing	6,538
2. Mining and quarrying	752
3. Crude Petroleum And Natural Gas & Metal Ores + coal	22,218
4. Other Mining and mining services	0
5. Food (and Tobacco)	7,135
6. Drink	1,413
7. Textile, Leather, Wood	2,846
8. Paper and Printing	4,851
9. Coke and refined petroleum products	34,648
10. Chemicals and Pharmaceuticals	2,310
11. Rubber, Cement, Glass	6,637
12. Iron, steel and metal	20,619
13. Electrical Manufacturing	2,481
14. Manufacture Of Motor Vehicles, Trailers And Semi-Trailers	1,834
15. Transport equipment l and Other Manufacturing (incl Repair)	2,756
16. Electricity, transmission and distribution	148,222
17. Gas; distribution of gaseous fuels through mains; steam and air conditioning supply	3,789
18. Natural water treatment and supply services; sewerage services	1,123
19. Water Management and remediation	1,095
20. Construction - Buildings	12,588
21. Wholesale and Retail Trade	13,900
22. Land Transport	2,689
23. Other transport	84,792
24. Transport support	3,270
25. Accommodation and Food Service Activities	4,122
26. Communication	1,126
27. Services	6,678
28. Education health and defence	17,894
29. Recreational	1,803
30. Other private services	92
Households	184,121
Total	604,343

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