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Decomposition Analysis of CO_2 Emissions with Emphasis on Electricity Imports and Exports: EU as a Model for ASEAN Integration

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This study analyses the potential implications of electricity trading to meeting the global emissions reduction targets. Global CO_2 emissions reached 32.4 Gt in 2014. Though the overall trend has been increasing, significant emissions reductions from Kyoto parties with targets have been achieved. The primary instrument for accomplishing this, has been the emissions trading system. Some scholars suggest electricity trading as an alternative. Electricity imports grew from 88 TWh to 510 TWh in OECD countries from 1974 to 2015. In non-OECD countries, the same was 238 TWh in 2014. Specifically, in the ASEAN, this is seen as a solution to looming energy security and pollution issues. Plenty of grid interconnections are being planned in the region. Through this study, learnings and policy implications from the EU are sought for the ASEAN region. Using decomposition analysis, the effects of imports and exports are compared against other traditional drivers such as population growth, economic activity and energy intensity. It is found out that France, Switzerland and Sweden are currently in the best position to export electricity in the region, because of their relatively large export capacities and very low carbon intensity for electricity generation. The results also show that electricity imports and exports are responsible for significant changes in CO_2 emissions from 1990 - 2014 in EU. Policy implications and learnings for ASEAN follow the results discussion.

1. Background

Global CO_2 emissions reached 32.4 Gt in 2014 – a 57.9 % increase from 1990 values (IEA, 2016a). Though the overall trend has been increasing, significant emissions reductions from Kyoto parties with targets have been achieved. 47 % of the committing parties have already met their reduction targets at the end of 2014. However, continuous increases in emissions from non-participating mega-economies, and developing countries, have overshadowed this achievement.

The European region has been at the forefront of sustainable energy movement. For example, Blumberga et al. (2014) outlines a roadmap for fossil fuel independence of Latvia by 2050. Majority of reductions have come from European Annex I countries (e.g. the UK, Sweden, Germany), and economies in transition (e.g. Belarus, Estonia), with the emissions trading system (ETS) as the primary tool (European Commission, 2017). Emissions trading is a system by which some countries get permits to emit carbon due to their commitment to cleaner generation. These countries may then trade these permits with other countries who need a larger carbon allowance to generate their energy needs.

Some scholars investigate the effectiveness of emissions trading as a long-term solution. Bode (2006) looked into policy design challenges for the system. A study by Kemfert (2007) observed that emissions trading apparently leads to higher electricity prices in the region. On a separate study, Nazifi and Milunovich (2010) concluded a short-run linkage between carbon allowance prices and electricity prices. While emissions trading promotes efficient use of energy resources, it does not directly affect the price of fossil fuels.

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In response, some scholars study the role of electricity trading as an alternative to emissions trading with regards to meeting the world's emission reduction targets (Hauch, 2003). Electricity trading refers to cross-border transmission of electricity (import/export). From a local perspective, some countries may exploit this means to reduce emissions occurring within their borders, and to meet their own emission targets. However, real reductions in global emissions can only be achieved if the generation mix of the exporting country is less carbon intensive than that of the importing country. This concept can have significant energy and climate policy implications if not regulated and monitored properly.

Electricity imports of OECD countries grew from 88 TWh in 1974 to 510 TWh in 2015 (IEA 2016b). Outside the OECD, countries reported electricity imports of 238 TWh and electricity exports of 215 TWh in 2014 (IEA, 2016b). In Southeast Asia, in light of ASEAN integration, it is also being mentioned as a way to move forward. According to IEA (2015), ASEAN have long supported the concept of interconnecting their power grids to facilitate cross-border electricity trade. Currently, Southeast Asia is a net electricity importing region, with the imports from China.

The study intends to explore potential policy implications for electricity trading in the light of meeting global climate targets. Potential learnings for the ASEAN are sought. The potential of electricity trading to curb global carbon emissions will be demonstrated via a case study in the European region, where plenty of data for analysis are currently abound. First, from a country perspective, local gains or reductions in CO_2 emissions due to electricity imports and exports are quantified using decomposition analysis. The use of decomposition analysis contextualizes these contributions with other traditional drivers, namely changes in population, economic activity, energy intensity, and carbon intensity. Afterwards, the study assesses whether these cross-border activities translate to actual reductions in global CO_2 emissions.

2. Literature Review

There is definitely a growing interest in the study of trade activities in lieu of sustainable development, such as in Liu et al (2015). Hauch (2003) suggested electricity trading as an alternative to emissions trading for meeting emission reduction targets. A demonstrative study was performed by Amor et al. (2011) to quantify the net avoided GHG emissions due to electricity trading by Quebec, Canada, with adjacent provinces. It was estimated that electricity imports to Quebec were responsible for 7.7 Mt of GHG, while the hydropower exports of Quebec avoided 28.3 Mt of GHG – resulting to a net reduction in emissions of 20.6 Mt. However, Unger and Alm (2000) touched on the reasons why electricity trading has yet to flourish as an alternative. According to the study, the economics of emissions trading hinder the exploitation of electricity trading to help meet emissions targets. The economic benefits from emissions trading simply outweigh the value of electricity trading. On a different note, Lilliestam and Ellenbeck (2011) consider the political and economic implications of electricity trade between Europe and North Africa through the Desertec concept. With the abundance of solar electricity in neighbouring North Africa, engaging in electricity trade will straightforwardly make Europe meet its emissions reduction targets. However, the study highlights concern on susceptibility to political pressure and extortion from this type of agreement.

3. Data and Methods

The study selected the European region for the case study due to its history and experience in electricity trading, and also due to abundance of available data for analysis. The top 20 countries with electricity trading activities with or within the European region have been selected for the analysis. The electricity generation carbon intensity of all other countries trading with them are also included in the study.

3.1 Data sources

The study utilized population data from the United Nations Department of Economic and Social Affairs (2015). The GDP of each country using constant 2010 US dollars were taken from the World Bank (2017). Due to data availability, the 1990 GDP of Hungary and Slovak Republic were extrapolated from 1991-1998 data. With regards to the electricity generation mix, power losses, and amount of electricity imports and exports, the study used data from the International Energy Agency (IEA) (2016c). Moreover, the electricity trading matrix was taken from the Fraunhofer Institute for Solar Energy Systems (2015). The electricity trading matrix provides information on which country is trading with whom, and by how much (in GWh).

Finally, with regards to estimating emissions, the study utilized the top-down approach outlined in Vol. 2, Ch. 6 of the "2006 Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Inventory Guidelines" (IPCC, 2006). The emission factors were taken from IPCC (1996) and the Environmental Protection Agency (2014).

3.2 Decomposition analysis using LMDI

The logarithmic mean Divisia index (LMDI) was introduced by Ang et al. (1998). It is used to quantify the contribution of driving forces (e.g. P, G, I, M, X and F) to a differential quantity, most common application of which is in energy consumption and emission reduction studies, such as in Sumabat et al. (2016). Similar studies have been done in Asia (Wang and Liu, 2016), and Europe (Papagiannaki and Diakoulaki, 2009). The identity function used in the decomposition analysis is shown in Eq(1). The identity function lists the assumed drivers to changes in CO_2 emissions in this study.

$$C_i = P \times \frac{Q}{P} \times \frac{E_d}{Q} \times \frac{L}{E_d} \times \frac{E_{d+e}}{L} \times \frac{C}{E_{d+e}} = P \times G \times I \times M \times X \times F \quad (1)$$

where C_i is carbon dioxide emissions (tCO_2) from country i; P is population; Q is GDP; E_d is domestic electricity consumption (GWh); L is amount of locally generated electricity (GWh); E_{d+e} is the sum of domestically consumed and exported electricity (GWh); C/E_{d+e} is the local carbon intensity (tCO_2/GWh). For the effects: P is population; G is economic activity; I is energy intensity; M is import effect (fraction of un-imported electricity); X is export (% increase in local generation due to export); and F is carbon intensity. The effects are calculated for each country using Eq. (2).

$$\Delta Effect_i = \frac{C^T - C^0}{lnC^T - lnC^0} \ln\left(\frac{Effect_i^T}{Effect_i^0}\right) \quad (2)$$

where *Effect* is any driving factor in general (i.e. P, G, I, M, X and F); i refers to country; C is carbon dioxide emissions due to local generation; T and 0 refer to the final time period and the base time period, respectively. The reader is directed to (Ang, 2015) for more discussion on the formulation and use of LMDI.

3.3 Determining net emissions savings due to electricity trading

To determine net emissions savings from electricity trading, the actual CO_2 emissions of generating the total imported electricity by each country is calculated first using Eq. (3). The carbon intensity for generation used is that of the exporting country.

$$C_{i-imp/a} = \sum_k E_k F_k \quad (3)$$

where $C_{i-imp/a}$ is the actual carbon emissions (tCO_2) due to total electricity imports of country i; E_k is the electricity imports of country i from country k; F_k is the generation carbon intensity of country k. The hypothetical CO_2 emissions of imported electricity, should they have been generated locally, are calculated using the carbon intensity for generation of the importing country (see Eq. 4).

$$C_{i-imp/h} = \sum_k E_k F_i \quad (4)$$

where $C_{i-imp/h}$ is the hypothetical carbon emissions (tCO_2) due to total electricity imports of country i; F_i is the generation carbon intensity of country i. The net emissions savings, $C_{i-imp/net}$, due to electricity importing is then obtained by simply subtracting the two quantities (see Eq. 5).

$$C_{i-imp/net} = C_{i-imp/h} - C_{i-imp/a} \quad (5)$$

Due to data availability, there are some critical assumptions or simplifications applied in the calculations for this study. First, carbon intensity for electricity generation is aggregated. The actual emissions due to the imported electricity are calculated using the aggregated carbon intensity for electricity generation of the exporting country. The same is true for calculating the hypothetical emissions of the imported electricity. It is assumed that the country would be using their existing energy mix, if ever they need to locally generate the imported electricity.

4. Results Discussion

The data presented are not cumulative of the years in between, but rather simply a comparison of the annual emissions of each country in 1990 and 2014. The largest electricity exporters in the region are France and Germany, followed by Switzerland, Sweden and Czech Republic. Almost everyone increased their electricity trading activity since 1990. With regards to carbon intensity of electricity generation, Sweden, Switzerland, France and Norway have the lowest, while Poland, Netherlands, Germany, Belarus and Czech Republic have the highest. It is notable how France, Switzerland and Sweden are currently in the best position to export electricity in the context of reducing global emissions. They are among the largest electricity importers while having the lowest carbon intensity for generation.

4.1 LMDI Results

With regards to interpretation, the various effects (i.e. population growth, increase in economic activity, etc.) are used as explanatory factors in the increase/decrease of CO_2 emissions. For example, we can have a look at Germany and see that the increase in its economic activity (GDP per capita) from 1990-2014 is responsible for 35 Mt CO_2, while its improvements in energy intensity (GWh/GDP) offset 35 Mt CO_2 in the same period (see Figure 1). In comparison to other drivers, the contributions of electricity exports to CO_2 emissions are more pronounced in countries with higher per capita CO_2 emissions (Figure 1). In these countries, the contributions of electricity exports are almost as large, or sometimes even larger than the contributions of population growth (i.e. Germany, Czech Republic, Netherlands, and Slovak Republic). For France, Sweden and Switzerland, who are relatively large exporters of electricity, the extra generation minutely affected their CO_2 emissions since they have very low carbon intensity for electricity generation, to begin with. The effects of importing electricity are not as noticeable, compared to exporting. Though notably, the increase in imported electricity of Netherlands helped lower its emissions between 1990-2014. The same outcome is observable with Germany, Great Britain, Belgium and Austria, but in lesser degrees.

Isolating the effects of imports and exports together with the total difference in emissions from 1990-2014 (see Figure 2), the role of electricity trading becomes more evident. For Germany, Czech Republic and Netherlands, their increases in electricity exports are responsible for a large part of their emissions increases from 1990-2014. With regards to imports, the increases in imported electricity of Germany, Netherlands, Austria, Great Britain and Belgium offset a large portion of their emissions from 1990-2014. In the case of Belgium, the amount of emissions offset by the increase in imports even outweigh the actual reductions from the country.

4.2 Net emissions savings

Using the procedure described in section 3.3, the net emissions savings from electricity trading is calculated (Table 1). This is using the electricity trading matrix from the Fraunhofer Institute for Solar Energy Systems (2016). Notably, the region saved a combined 10.3 Mt CO_2 due to electricity trading in the region. This is largely in part due to the significant amount of electricity exports coming from France, Switzerland and Sweden, which are relatively coming from clean energy sources. This finding validates the potential of electricity trading to assist in meeting large scale regional emission reductions targets.

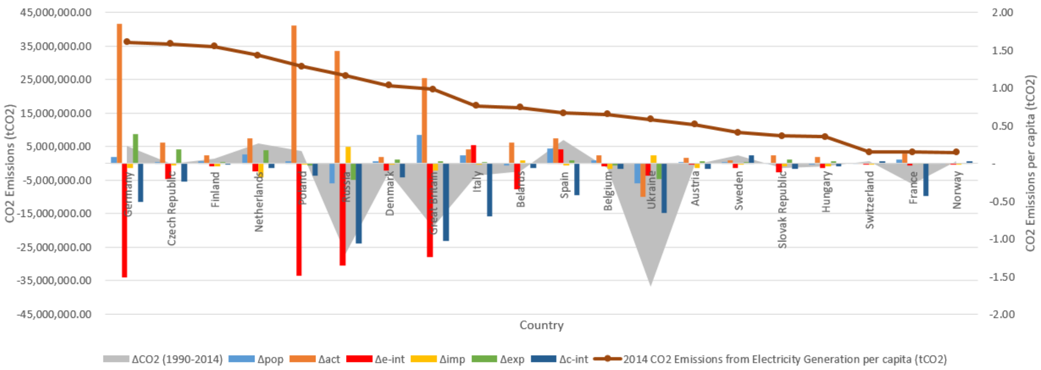

Figure 1. Summary of effects in the period 1990 - 2014. ∆pop, population effect; ∆act, economic activity effect; ∆e-int, energy intensity effect; ∆imp, import effect; ∆exp, export effect; ∆c-int, carbon intensity effect.

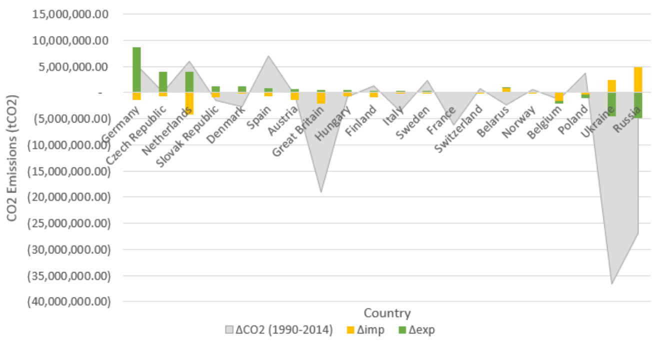

Figure 2. Relative contribution of import and export effects to ΔCO_2 from 1990-2014.

Table 1. Net emissions savings by each country, due to electricity imports (tCO_2)

Country	Emissions savings due to electricity importing (t CO_2)	Country	Emissions savings due to electricity importing (t CO_2)
Italy	6,016,604.06	Belarus	39,726.71
Germany	5,009,002.39	Norway	- 396,554.41
Netherlands	2,395,636.10	Belgium	- 397,420.64
Great Britain	2,174,922.42	Russia	- 443,435.56
Poland	2,034,192.95	Sweden	- 550,340.04
Finland	1,727,091.21	France	- 649,325.33
Denmark	1,262,286.62	Czech Republic	- 915,012.74
Hungary	466,690.50	Slovak Republic	- 2,001,392.53
Spain	447,445.85	Switzerland	- 2,544,920.21
Ukraine	187,591.75	Austria	- 3,560,663.23

5. Policy implications and learnings for ASEAN

Exploitation of large available renewable energy resources for regional use

The countries with lower carbon intensity for electricity generation, or rather, electricity generated from renewable sources must be given priority in the import/export market. Europe benefitted with the large amounts of clean energy exports from France, Switzerland and Sweden.

Improved reporting system for electricity trading

Currently, electricity trade is used as a balancing item for countries when reporting electricity flows (IEA, 2016b). This leads to considerable variation in import and export data. Provisions for more detailed inventory of wheeled electricity is also needed. This is electricity generated from country A, imported by country C, but had to be transmitted across the grid of country B. Fuel-specific electricity trading information is also critical.

Strong regulatory and a centralized managing body

This is to prevent possible use of the "energy weapon" to extort and politically pressure countries in the region. As experienced in Europe, and discussed by Lilliestam and Ellenbeck (2011), strong dependency on imported electricity makes a country susceptible to such issues. It is recommended that countries do not import more than what they have as back-up power.

Planning for seasonal renewable resource availability and electricity trading

It is common for countries to import plenty of electricity during the summer season due to air conditioning. The increase in demand during this season usually forces plenty of countries with a usually clean generation mix to use electricity from fossil-based sources because of generally lower prices. Careful planning and strategizing for availability of resources should be done.

6. Conclusions and Recommendations

The study contemplates on the concept of utilizing large-scale electricity trading in order to meet global emission reduction targets, especially in integrated regions such as the EU and ASEAN. This can potentially maximize renewable energy resources which may be concentrated on specific, geographically-gifted countries. Through the study's estimates, the European region had a net emissions savings of 10.3 Mt CO_2 from 1990 - 2014, simply due to electricity trading. It is a meager amount compared to the region's actual emissions, but there is huge potential to increase this through a conscious effort. This result validates the potential of electricity trading to aid in meeting global emissions reduction targets.

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