SOCIOECONOMIC SPILL OVERS OF THE EUROPEAN ELECTRICITY NETWORK DEVELOPMENT PLAN

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ABSTRACT

Over the next decades, there will be more electricity transmission investment in most IEA regions to incorporate renewables and to improve electricity market integration. The Ten Year Network Development Plan (TYNDP) 2016 has anticipated up to €125 bn of investments in grid infrastructure supporting 200 projects in transmission and storage by 2030. In addition to the cost-benefit assessment of transmission projects, which is mandated by the European Network of Transmission System Operators for Electricity (ENTSO-E), information on the potential socioeconomic impacts will support the sustainable development of the interconnector projects. This study sheds light on the national and cross- border spill over effects of the future electricity infrastructure investment in Europe.
We estimate the infrastructure investment cost per MW-km and employ a multiregional input-output (MRIO) table to determine the percentage allocation of the cost over the sectors that deliver the required goods and services for electricity transmission. Then we evaluate the environmental and socio-economic effects of a network investment of 2300 MW of electricity transmission between Ireland-UK and Ireland-France by 2030 in the MRIO model. For the selected countries, the input coefficients of non-domestic goods and services to the electricity transmission vary between 0.03 to 0.18. The cross-border spill overs for value-added, employment numbers, GHG emissions and particulate matter emissions for the future investment in electricity transmission are assessed for EU and non-EU countries.
The study discusses the global socio-economic impacts of wind transmission investment as the dominant renewable electricity source and does so from the perspectives of future energy scenarios.

1. INTRODUCTION

Europe has set very ambitious climate goals in the last years. Back in 2009, the Renewable Energy Directive 28/2009/EC, also known as RED, set national binding renewable electricity supply (RES) targets that together would lead to a 20% renewable energies penetration in final energy consumption in 2020 (The European parliament and the council of the European Union, 2009). The European Commission published, as part of the 2030 framework for climate and energy, a proposal for a revised Renewable Energy Directive to make the EU a global leader in renewable energy and ensure that the target of at least 27% renewables in the final energy consumption in the EU by 2030 is met (European Comission, 2017).
These ambitious renewable energy targets in final energy entail, as the main energy scenarios published, show very high renewable power integration in the European national power systems (European Commission, 2016). In this context, European countries will need to increasingly rely on each other through cross-border exchanges and this new

framework of increased cooperation would need more interconnection capacity at borders, and also reinforcements of national grids. Back in 2015 the European Parliament (EUROPEAN PARLIAMENT, 2015) stablished a 10% interconnection target in 2020 meaning that electricity interconnection capacity should be at least 10% of the installed electricity capacity in each country. The new 2030 framework for climate and energy proposed by the EC sets a 15% target for 2030.

Currently, cross border interconnections are not sufficient to allow a well-functioning internal energy market in Europe. The latest report on the state of the Energy Union (European Commission, 2017) finds that 11 Member States (Bulgaria, Cyprus, Germany, Spain, France, Ireland, Italy, Poland, Portugal, Romania, United Kingdom) have not yet reached the 10 % electricity interconnection target and that four of them (Cyprus, Spain, Poland, United Kingdom) will be unable to do so by 2020.

The European Network of Transmission System Operators for Electricity (ENTSO-E) estimated that a fully integrated EU electricity market could save users up to €43 billion a year on average (ENTSO-E, 2018). The reasons behind these savings are that the increase in the transmission capacity between countries could decrease electricity market prices in most of the countries, strengthening security of supply and allowing the integration of a high share of RES in the system. A literature review made by (Booz & Company, 2013) found benefits ranging from 1-10% of system costs. Similar results were confirmed by (Schmid and Knopf, 2015) that when new transmission lines are not allowed, system costs are higher by 1.9%. Costs drivers are the use of less favourable wind and solar energy resources, higher curtailment rates, and the need to invest in more costly renewable energies or storage technologies. (Schmid and Knopf, 2015) also confirm these earlier findings that increasing interconnection capacity among European Member States is a no regret option.

However, Member States would need to invest to interconnect their national grids. In this sense, the implementation of the projects necessary for the connection of the European energy markets is one of the political priorities of the European Union for 2018. Many of these infrastructure projects are oriented towards improving electricity interconnection between the Member States.

The Ten Year Development Network Plan (TYDNP) published by ETSOE in 2016 provides a detailed study of the needs of the power system of tomorrow in terms of increased interconnections. It foresees around 125 billion euros of investments in grid infrastructure supporting 200 projects in transmission and storage. This amount is largely below the expected benefits in most circumstance.

In addition to the direct economic benefits of a fully integrated electricity market, there are number of other external benefits. On the environmental side, the reduction of RES curtailment and the optimization of economic dispatch would also lead to reductions in CO_2 emissions (Tractebel Engineering, 2016; Pöiry, 2016). As for the potential socioeconomic impacts, the investments needed and the increased domestic renewable energy use would boost economic growth and employment creation (United Nations, 2006). This effect would be especially relevant in member states at the European periphery where some of them have been severely hit by the economic crisis. Recently the Expert Group on electricity interconnection targets recognised that investments in interconnectors might have a positive socio-economic impact, as a positive spill over, and offer opportunities to maintain and strengthen employment (Expert Group on electricity interconnection targets, 2017). However, the analysis of these cross border indirect effects and spill overs in a cost benefit analysis of electricity interconnections are largely neglected in literature that focuses on the operational effects of such infrastructure.

The spill over socioeconomic effects of energy infrastructure investment expenditure has been analysed in the literature especially for gas pipelines. Bouwmeester and Scholtens (2017) evaluated the effects on employment of investment expenditures of five Western European countries using Multiregional Input-Output methodology (MRIO), distinguishing between domestic impacts, impacts in other EU countries, and non-EU impacts. Similar analysis for electricity interconnectors has not been found in the literature. This paper contributes to enlarging the literature in this topic by providing a method to quantify these spill overs and the indirect cross-border impacts of investment expenditures in electricity interconnection infrastructure. There are several methodologies able to estimate these socioeconomic effects. Among them multiregional input-output (MRIO) model is one of the preferred methodologies by the scientific community. The paper applies a MRIO simulation model to analyse the potential socio-economic effects of the investment of interconnectors between Ireland, France and Great Britain.

2. METHODOLOGY

The input-output (IO) analysis began as a method to analyse national or regional economies as interconnected systems of industries that affect each other directly or indirectly. However, production processes have become less domestic, and national economies are actually part of a global economy. Supply chains are increasingly fragmented across borders and this fundamentally modifies the nature of international trade with important consequences for the location of production as well as other related impacts. MRIO modelling provides an opportunity to analyze the consequences of this fragmentation in a comprehensive way by including different regions and their trade relationships.

Complementing the IO tables' information with data about sectorial employment creation or greenhouse gas emissions (GHG) by sector, MRIO analysis allows the estimation of the economic, employment and environmental impacts of an investment in any sector or industry and its upstream sectors or industries that are directly and indirectly stimulated. It is also a useful analysis to show the leakages effects between sectors and countries.

The study uses the Exiobase 2 MRIO dataset and simulate a model to assess the potential socioeconomic impacts of three TYNDP interconnectors of 2,300 MW between Ireland, Great Britain and France. Exiobase is a multiregional environmental database that includes 48 countries and 163 industries (Tukker, 2013). The development and features of this database are explained by (Tukker, 2013; Wood, 2014). Besides the economic impacts of the transmission investment, the study focuses on potential GHG emissions and particulate matter derived from this project, direct and indirectly, as well as on employment.

Input-output (IO) analysis was developed by Wassile Leontief, who represented the inputs required to produce a unit of output in each economic sector based on the accounting surveys from industries and companies in a symmetrical tables called IO Tables (Leontief, 1941). The IO tables comprise two main components, the inter-industry flows or transaction matrix, which describes the flows from sector i to sector j, and the final demand. Intermediate goods and services are those, which will be further processed by other sectors. The following table represents the main components of an IO table.

Table 1. Example of input-output table.

		Processing sectors (intermediate demand)				Final demand	Total output
		1	2	…	n		
Processing sectors	1	z_{11}	z_{12}	…	z_{1n}	y	x
	2	z_{21}	z_{22}	…	z_{2n}		
	…	z_{31}	z_{32}	…	$z_{..n}$		
	n	z_{n1}	z_{n2}	…	z_{nn}		
Payment sectors	Value added	v_1	v_2	…	v_n		
	Import	m_1	m_2	…	m_n		
Total outlays		x					

Total output from one sector is described by the following Eq. 1- Eq. 5:

$$x_i = z_{i1} + z_{i2} + \cdots + z_{in} + y_i$$

Eq.1

This equation will be set for all sectors included in the IO table and can be described using matrix notation:

$$x = \begin{bmatrix} x_1 \\ \cdots \\ x_n \end{bmatrix} ; \quad Z = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nn} \end{bmatrix} ; \quad y = \begin{bmatrix} y_1 \\ \cdots \\ y_n \end{bmatrix}$$ Eq.2

where x is a vector that expresses the total output, Z is the IO matrix and y is the final demand vector.

Leontief normalized the cost requirements by sector through the technical coefficients which are denoted as:

$$a_{ij} = z_{i1}/x_j$$

Eq.3

The technical coefficients can be expressed as a matrix, as well, and by substituting z_{ij} in equation 1 for the technical coefficients, the total output can be defined by the following matrix equation:

$$x = Ax + y$$

Eq.4

Reorganizing equation 4, we get the following expression:

$$x = (I - A)^{-1} y$$

Eq. 5

where $(I - A)^{-1}$ is the Leontief inverse matrix, or the multiplier matrix, that expresses the total production of each sector required to satisfy the final demand. That is the direct and indirect requirements per unit of final demand.

Through the IO analysis, it is possible to analyse the economic impacts in an economy derived from a change in the final demand of goods and services, such as new infrastructure development and planning.

To include any extension, environmental or social, we need to have an additional matrix or vector that provides the amount of pollutants, i.e., emitted by each activity sector per monetary unit of output. Including this vector into equation 5, we get the final expression that we have used in this study:

$$e_i = l_i (I - A)^{-1} y$$

Eq. 6

where l_i is the vector describing the direct impacts coefficients (per unit of output) and e_i is the total impact , direct and indirect, associated to the total output that satisfies the final demand.

At this point, we should be able to analyse the potential impacts, both economic and environmental, associated with a change in the final demand. However, due to the limited number of sectors included in the database, we cannot assign the final demand required by the project to one unique sector, which would produce or fulfil the demand, such as transmission grid sector. In order to surpass this aggregation problem, we have done a step back, defining all goods and services required to get our final product, which are the transmission lines. The final demand vector describes then the technical coefficient for the transmission lines, as an intermediate sector but is treated exogenously as a final demand. The estimation of the transmission expenditures and coefficients are presented is section 2.1 and 2.1.1.

2.1. TRANSMISSION INVESTMENT

The TYNDP projects listed in 2016 of transmission infrastructure between Ireland, UK and France is listed in Table 2. Only the projects that match with the TYNDP reference capacities and with the European Commission's draft guidelines are listed.

Table 2. Interconnector plan (TYNDP, 2016) and estimated investment cost of the transmission infrastructure.

Interconnectors Promotors	Description	Reference capacity MW [2]	km	Expected Year	Estimated cost €m [3]	Specific estimated cost €/MWkm[4]	More information
Ireland-Norther Ireland EIRGRID;SONI	A 400 kV interconnector between Ireland, Woodland and Turleenan, UK. High voltage overhead lines.	600	138 km (34 km in north) Overhead lines	2019	286	3454	here
Ireland-Northern Ireland North West (RIDP I) EIRGRID;SONI	Facilitate connection of renewable generation and integrate Ireland-UK for sustainable demand growth.	500	113 km HVDC cable	2030	475	8407	here
Ireland-France (Celtic) EIRGRID;RTE	HVDC from Cork, Ireland to La Martyre, France. A direct link between the French and Irish markets but also increase RES integration, especially wind.	700	600 km 500 (Subsea) 100 (Underground)	2025	1000	2380	here here
Ireland-Wales UK Greenlink Element Power	Onshore underground cables utilising HVDC subsea and onshore cable.	500	172	2020-2025	500	5814	here & here

[1] High Voltage Direct Current
[2] The reference capacities from TYNDP is different from the provisional capacity of the plan.
[3] Whenever there are several cost scenarios, the first option and the most economic one is considered as the likely one in the study.
[4] Includes the cost of substations. An equal share between parties are assumed.

2.1.2. EXPENDITURE COEFFICIENTS OF ELECTRICITY TRANSMISSION

The transmission investment affects the model exogenously as a vector of final demand (Bouwmeester, 2017). The life cycle cost inventory data of the transmission infrastructure determines the share of expenditures paid domestically or internationally. These cost factors are obtained from the electricity transmission sector within the Exiobase 2[1]. It is assumed that the interconnectors are for increasing the share of wind electricity in the three regions. Table 3 summarizes the information on the total electricity generation and the share of wind energy for the base year 2007. The estimated coefficients which are obtained from the database are summarized in Fig. 1.

3. RESULTS AND DISCUSSION

There are potential local and international environmental and socio-economic impacts from the network infrastructure expansion. This paper highlights some of these impacts through a multiregional input-output (MRIO) simulation. The model facilitates tracking the impact from expenditures paid to various local and international sectors. These sectors include

[1] The Exiobase data is freely available at https://www.exiobase.eu/.

Table 3. Estimated share of electricity transmission cost in the base year.

Country	Total inter-industry transmission cost m€ [1]	Total GWh electricity generated in base year [2]	Actual GWh wind generated in base year [2]	% factor of wind electricity	Common efficiency factor of wind energy [3]	Average transmission expenditures in database [1] €/kWh
France	2686	569840	4140	0.069	0.19	0.007
Ireland	301	28230	1958	0.007	0.21	0.014
Great Britain	7117	394000	5300	0.014	0.25	0.030

[1] Obtained from EXIOBASE$_{V2}$, electricity transmission sector.
[2] The total electricity production and wind energy production for the base year 2007.
[3] Cumulative installed capacity can be obtained by multiplying the actual GWh of wind generated in the inverse of the efficiency and 8760 hours.

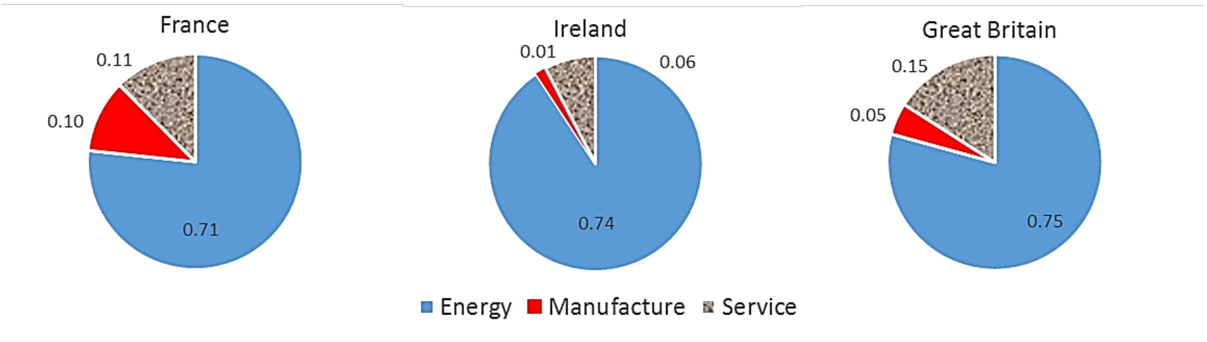


Fig. 1. Distribution of electricity transmission expenditures paid to various sectors. The balance accounts for trades.

manufacturing industries, energy sectors as well as services. In Table 4, the environmental and socio-economic flows of the three interconnectors are normalized per MW interconnection line between Ireland, France and Great Britain.

Table 4. Environmental and economic flows of the three TYNDP electricity interconnectors.

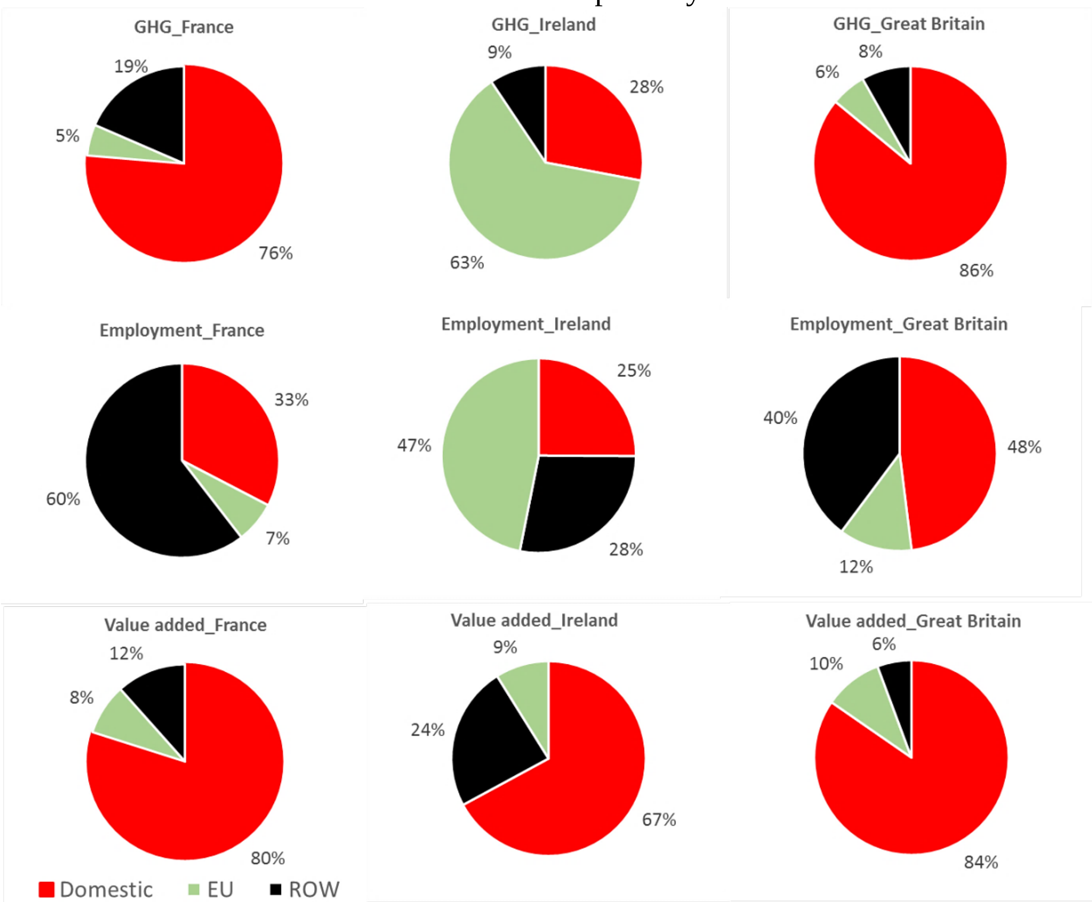
Indicator	France	Ireland	Great Britain
GHG emissions (t CO2-e/MW)	1113	2409	746
PM emissions (t/MW)	0.4	0.7	0.2
Employment (persons/MW)	30	13	11
Value-added (€m/MW)	1.43	0.98	0.79

The infrastructure of these new interconnectors is associated with GHG emissions. However, through the interconnectors, the surplus power generation capacity in a country can be used in another country with a constrained capacity (Madrigal, 2010) which reduces the GHG emissions. This is particularly important for grids which import a large amount of fossil fuel, such as Ireland. The results shown here do not reflect the net impacts derived from this potential substitution, which will be investigated in the next steps of this research.

The percentage factor of the total impacts in Table 4 is illustrated for the GHG emissions, value added and employment numbers are seen in Fig. 2. The regions are divided into the domestic, other European countries and non-European countries. For instance, to satisfy the expenditure demand of the Ireland interconnectors (Fig. 2), from the total GHG emissions, 28% is associated to the own country's production, 64% to the production by other European countries and 9% to the production by other non-European countries. Similarly, the impacts can be read from the table for France and Great Britain.

GHG emissions from electricity interconnectors per MW are from 2.2 to 3.2 times higher in Ireland than in the other countries. However, the domestic share of these GHG emissions is much higher in France and Great Britain than in Ireland. Domestic emissions are then not so different among countries and the larger emissions of Ireland are in fact produced in other EU countries.

Regarding employment generation per MW, interconnector's expenditures in France generate the largest number of full-time employees, almost double than in the other countries. However, 67% of the total employment in France has spilled over abroad (Fig. 2). The domestic shares of value-added are the highest in the three countries, mainly because a large portion of the transmission expenditure is paid to the energy sector itself. Ireland shows 17-23% lower production of domestic value-added compared to Great Britain and France. The country's dependency on fossil fuel imports for energy could possibly be a reason for that.



	France (%)			Ireland (%)			Great Britain (%)		
Domestic industries	GHG	Employ-ment	Value-added	GHG	Employ-ment	Value-added	GHG	Employ-ment	Value-added
Energy	21	23	54	95	45	81	90	23	64
Other manufacturing	76	22	12	1	10	4	8	9	4
Services	3	55	34	4	45	15	2	68	32

Fig. 2. Percentage factors of potential socio-economic impacts of three interconnectors.

The impacts illustrated in Fig. 2 do not consider the effects of additional power generation through new transmission networks. The domestic share of all indicators is relatively high in the three countries. The domestic sectors are aggregated to energy sectors, other manufacturing sectors and services, and the share of indicators in each aggregated sector is shown in the table at the bottom of Fig. 2.

In Fig. 2, the spill over effects of employment in other European countries and the rest of the world is significant in all three countries. These spill over factors are screened for countries with at least 2% employment effect and results are shown in Fig. 3. For instance, from the 60% spill over employment in the rest of the world for the France interconnector, around 30% occur in Africa (not-including South Africa), and so on.

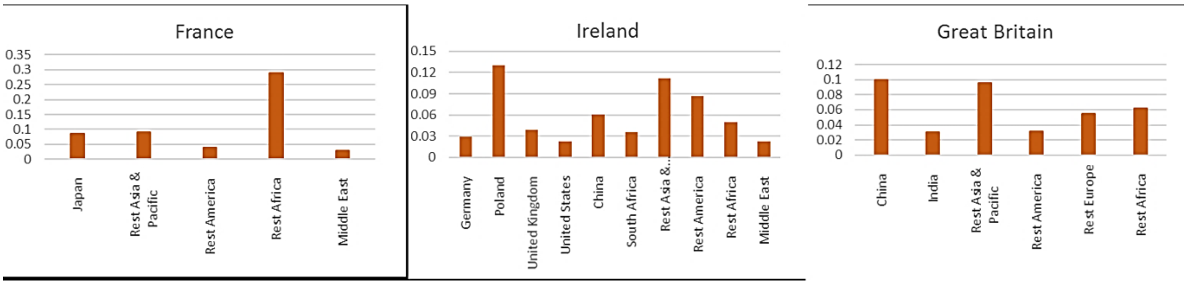


Fig. 3. Interconnectors spill over employment in the rest of the world.

The result of the MRIO simulation of three interconnectors investment sheds light on the direct and indirect environmental and socio-economic benefits (or losses in case of emissions) for the primary investor countries, as well as for the rest the world.

4. PERSPECTIVE OF FUTURE STUDY

The study investigates the socio-economic spill over of interconnector investment as the only parameter. However, there are other important parameters to consider, such as the expenditures and incomes from electricity production, demand changes, changes in fuel types of electricity generation, changes in taxes policies, and market conditions (e.g. tariffs which may be important in the light of Brexit). A better understanding of the international value-chains of European electricity interconnectors would be achieved when more scenarios are created to include these parameters in future studies. A sensitivity analysis of the main assumptions of the future interconnector expenditures simulated in the model can also be included in future studies.

5. CONCLUSIONS

The result of this study shows the potential of socio-economic effects of future transmission interconnection between Ireland, Great Britain and France under certain assumptions of a multi-regional input-output (IO) analysis. The latest available Exiobase 2 is used to simulate an IO model.

The transmission expenditures of the future 2300 MW electricity interconnectors for the total cost of 2261 €m, which will be paid to the domestic and international sectors, are exogenously modelled for Ireland, France, and the Great Britain. The potential flows of GHG emissions, particulate matter emissions, employment numbers and value-added per each MW interconnector is evaluated for the three countries. The impacts are broken down to show the percentage share of the investor country, the rest of the Europe and rest of the world. The result of this study provides a useful overview of the direct and spill over impacts of interconnector investments on the whole globe.

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