ECO-EFFICIENCY ASSESSMENT OF THE ELECTRICITY SECTOR: EVIDENCE FROM 28 EUROPEAN UNION COUNTRIES

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Outline

- It is imperative to reduce energy consumption and emissions;
- With this regard EU economic policy made eco-efficiency a relevant issue;
  - Determines economic and environmental success;
  - Enables identification of trends;
  - Helps to design action plans;

$$Eco - efficiency = \frac{Economic\ Value}{Environmental\ Impact}$$

- Eco-efficiency assessment:
  - **Environmental Extended Input-Output tables;**
  - **Data envelopment analysis;**

EEIO TABLES:

- Depict economic transactions among different activity sectors and enable the incorporation of environmental impacts linked to them;

DATA ENVELOPMENT ANALYSIS

- Non-parametric approach that allows assessing the relative efficiency of a set of DMUs;
- Increasing research interest due to the fact that electricity sector is one of the biggest GHG emitters.
- Drawbacks in the literature:
  - Research focus: Evaluation of environmental impacts taking mainly into account fuel consumption;
  - Ignore economic and social impacts;
  - Disregard separation of production and consumption chains;
  - Data used in these studies dates back to 2010;

PURPOSE:

- Fill the gaps of eco-efficiency assessment of the electricity sector
  - Evaluation of 28 EU countries through the use of EEIO tables in conjunction with DEA, considering the years of 2010 and 2014

INSPIRATION:

1. Lábaj et al. (2014) – Economic growth in terms of welfare in 30 European countries using DEA models;

2. Zurano-Cervelló et al. (2018) – Evaluate the eco-efficiency in the manufacturing sectors both considering production and consumption-based approaches using DEA models combined with IO tables;

NOVELTY:

- Application of the EEIO tables combined with DEA DDF, taking into account the production and consumption supply chains of the electricity sector.

STEP 1: SELECTION OF INPUTS AND OUTPUTS

Table 1. A review of studies which combine DEA with IO analysis

Reference	Application	Inputs	Outputs	Models used
Luptacik and Bohm (2006)	Eco-efficiency in an IO model	Labour; Capital	Pollutant Abatement activities	Augmented IO model; CCR; BCC (Banker, 1984); SBM
Luptacik and Mahlberg (2013)	Eco-efficiency and eco-productivity change over time in an IO model Austria (1995 - 2007)	Labour; Capital	Final demand; Air emissions	Augmented Leontief IO model; CCR Malmquist-Luenberger index
Lábaj et al. (2014)	Eco-efficiency and socio-economic efficiency in terms of welfare 30 European countries (2010)	Labour; Capital	Gross Domestic Product (GDP); Emissions	BCC
Zurano-Cervelló et al. (2018)	Eco-efficiency assessment of EU manufacturing sectors 27 EU countries (2009)	Global warming potential (GWP); Potential Acidifying equivalent (PAE); Tropospheric ozone forming potential TOFP)	Total economic output	Multi Regional EEIO tables; CCR; Super-efficiency

STEP 1: Selection of Inputs and Outputs

Inputs	Definition	Units
1 – Labour	Number of jobs in full time equivalent (FTE)	1000 employees
2 – Capital stock	Nominal Capital Stock (K)	10^6 €
3 – GHG missions	GHG emissions	1000 ton CO2 eq.
4 – ACG emissions	Acidifying gas (ACG) emissions	1000 ton SO2 eq.
5 – O3PR	Ozone precursors (O3PR)	1000 ton NMVOC eq.
Outputs	Definition	Units
GVA	Gross Value Added (GVA) - Monetary value for the amount of goods and services that have been produced, less the cost of all inputs and raw materials that are directly attributable to that production.	10^6 €

DIRECT PRODUCTION CHAIN STATISTICS – 2010 TO 2014

- Decrease of environmental emissions and labour;
- Capital stock and GVA increase;

Descriptive statistics of all DMUs in average – Direct production chain;

	Labour (X1000)	K (x10^6)	GHG (x1000 ton)	ACG (x1000 ton)	O3PR (x1000 ton)	GVA (x10^6)
2010	47 ↓	39,002 ↑	47,401 ↓	122 ↓	82 ↓	8,108 ↑
2014	45	44,493	41,284	87	68	8,432

DIRECT CONSUMPTION SUPPLY CHAIN STATISTICS – 2010 TO 2014

- Decrease of environmental emissions and Labour;
- GVA increase;

Descriptive statistics of all DMUs in average – Direct consumption supply chain;

	Labour (X1000)	GHG (x1000 ton)	ACG (x1000 ton)	O3PR (x1000 ton)	GVA (x10^6)
2010	20 ↓	3,344 ↓	8 ↓	7 ↓	1,489 ↑
2014	19	2,861	6	6	1,598

- Top 5 sectors that most contribute to emissions:
  - D35 (Electricity), B (mining and quarrying), H49 (Land transport and transport via pipelines), C19 (coke and refined petroleum), E37-E39 (Sewerage; waste collection …);

INDIRECT CONSUMPTION SUPPLY CHAIN STATISTICS – 2010 TO 2014

- Decrease of environmental emissions and Labour;
- GVA increase;

Descriptive statistics of all DMUs in average – Direct consumption supply chain;

	Labour (X1000)	GHG (x1000 ton)	ACG (x1000 ton)	O3PR (x1000 ton)	GVA (x10^6)
2010	36 ↓	18,334 ↓	47 ↓	33 ↓	4,032 ↑
2014	35	16,418	34	28	4,291

- Top 5 sectors that most contribute with emissions:
  - D35, B, H49, C23 (non-metallic mineral products), E37-E39;

PRODUCTION CHAIN

Descriptive statistics of efficient DMUs – direct production chain

	Labour (X1000)	K (x10^6)	GHG (x1000 ton)	ACG (x1000 ton)	O3PR (x1000 ton)	GVA (x10^6)	Super efficiency score
2010	62	61,572 ↑	55,679 ↓	105 ↓	84 ↓	13,264 ↓	1.87 ↓
2014	62	67,289	53,437	99	78	13,205	1.80

Descriptive statistics of inefficient DMUs – direct production chain

	Labour (X1000)	K (x10^6)	GHG (x1000 ton)	ACG (x1000 ton)	O3PR (x1000 ton)	GVA (x10^6)	Efficiency score
2010	36 ↓	22,074 ↑	41,192 ↓	134 ↓	81 ↓	4,240 ↑	0.86 ↓
2014	33	27,397	32,169	78	61	4,853	0.84

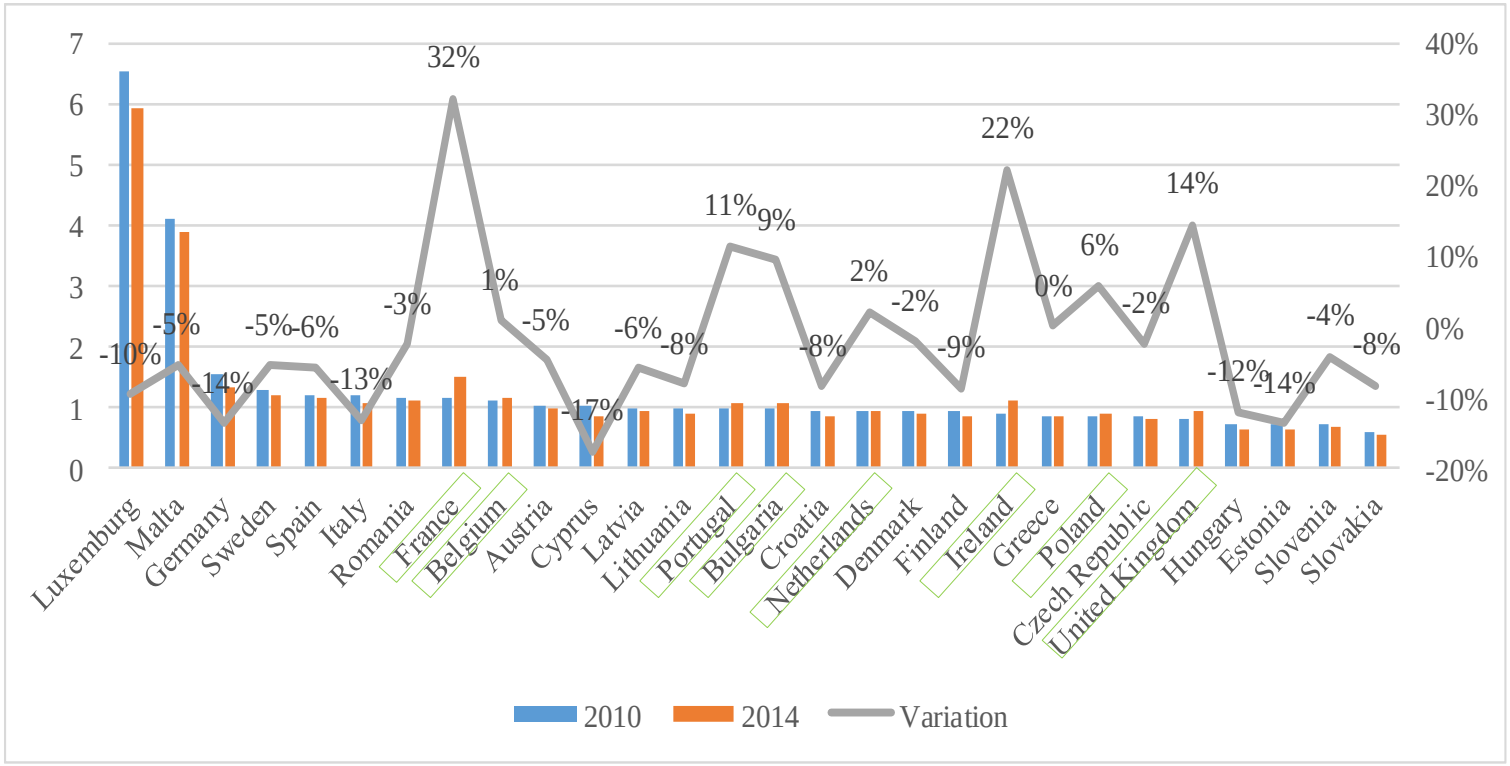
PRODUCTION CHAIN

Data and efficiency scores obtained in the direct production chain in 2010 and 2014

DMU	2010		2014	
	Super-Efficiency Score	Nº of times as Ref.	Super-Efficiency Score	Nº of times as Ref.
Luxemburg	6.55	6	5.92	7
Malta	4.10	10	3.88	7
Germany	1.54	9	1.33	1
Sweden	1.28	3	1.21	3
Spain	1.22	4	1.15	3
Italy	1.22	0	1.06	0
Romania	1.16	6	1.13	5
France	1.15	1	1.52	8
Belgium	1.14	9	1.15	4
Austria	1.04	0	0.99	0
Cyprus	1.03	2	0.85	0
Latvia	1.01	0	0.95	0
Portugal	0.97	0	1.08	2
Bulgaria	0.97	0	1.06	2
Ireland	0.90	0	1.10	13
Hungary	0.75	0	0.66	0
Estonia	0.73	0	0.63	0
Slovenia	0.72	0	0.69	0
Slovakia	0.61	0	0.56	0

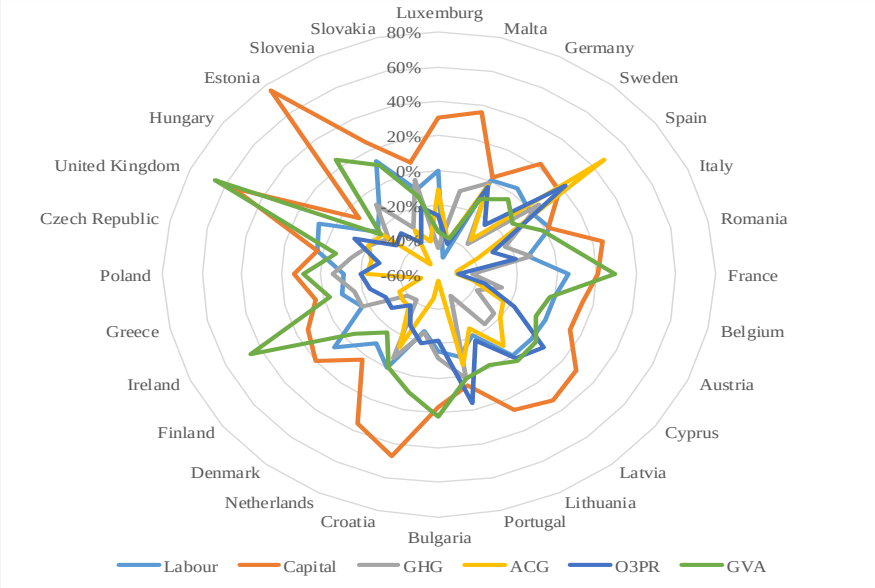
PRODUCTION CHAIN

Super efficiency scores in 2010 and 2014 - Direct Production Chain



PRODUCTION CHAIN

Changes of inputs and outputs between 2010 and 2014 – Direct Production Chain



Portugal, Ireland and Bulgaria:
– Increase GVA and improve the productivity of K and Labour with a reduction of fossil fuel generation (20%, 21% and 5%) and increase production of renewable energy (13%, 72% and 24%);

France increases K and GVA and decreases emissions;

Belgium increases K, decrease GVAs and emissions;

Cyprus, Latvia and Austria keep level of labour and decrease emissions;

Cyprus and Latvia considerably augment k and slightly GVA;

Austria increases slightly K but decreases GVA.

DIRECT CONSUMPTION SUPPLY CHAIN

Descriptive statistics of efficient DMUs – direct consumption supply chain

	Labour (X1000)	GHG (x1000 ton)	ACG (x1000 ton)	O3PR (x1000 ton)	GVA (x10^6)	Super efficiency score
2010	34 ↓	7,057 ↓	13 ↓	15 ↓	3,331 ↓	1.56 ↑
2014	27	4,492	8	10	2,897	2.73

Descriptive statistics of inefficient DMUs – direct consumption supply chain

	Labour (X1000)	GHG (x1000 ton)	ACG (x1000 ton)	O3PR (x1000 ton)	GVA (x10^6)	Efficiency score
2010	13 ↑	1,586 ↑	5	4	616 ↑	0.61 ↓
2014	15	1,955	5	4	876	0.57

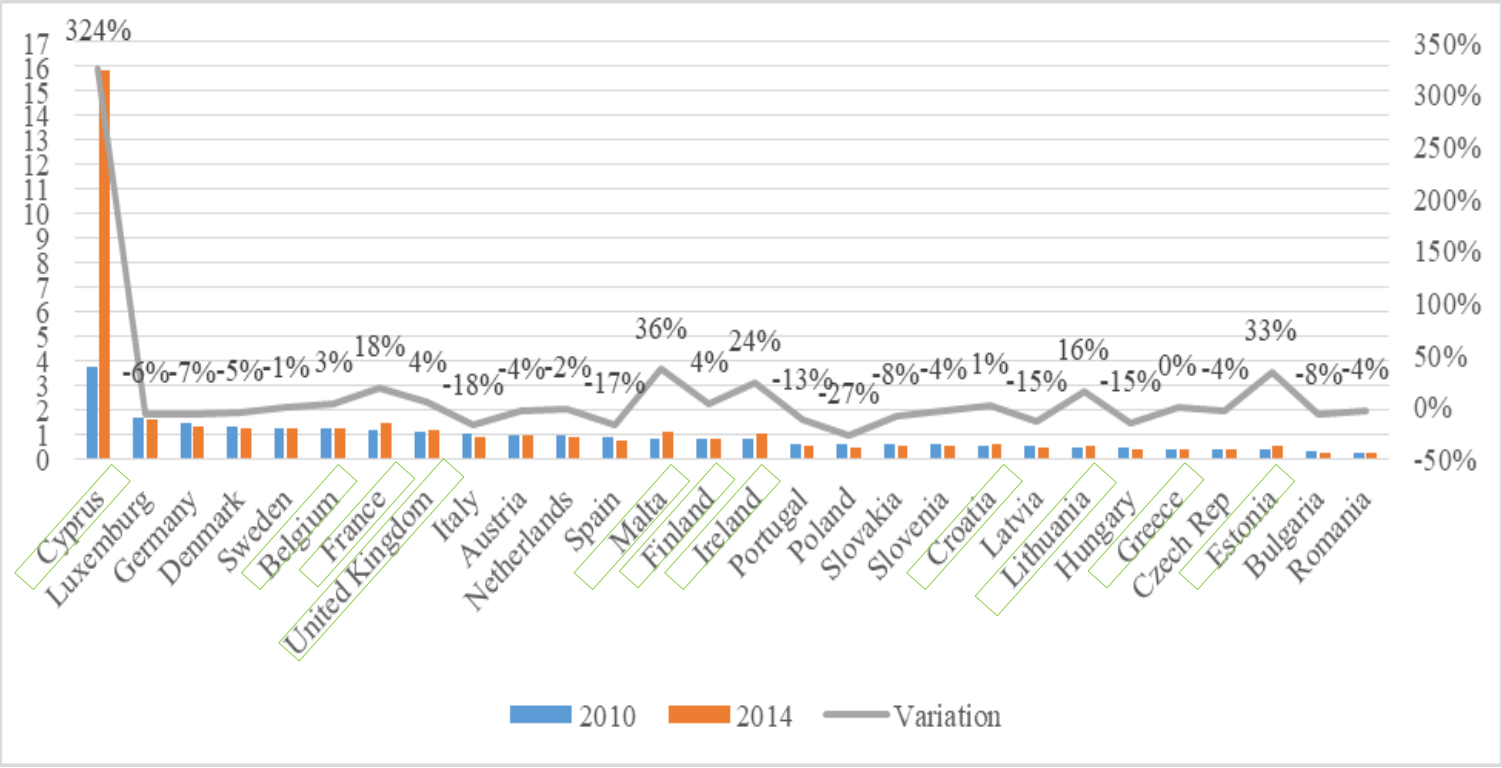
DIRECT CONSUMPTION SUPPLY CHAIN

Data and efficiency scores obtained in the direct consumption supply chain in 2010 and 2014

DMU	2010		2014	
	Super-Efficiency Score	Nº of times as Ref.	Super-Efficiency Score	Nº of times as Ref.
Cyprus	3.740	0	15.868	10
Luxemburg	1.686	15	1.579	2
Germany	1.455	2	1.352	0
Denmark	1.291	13	1.230	15
Sweden	1.274	13	1.263	10
Belgium	1.219	3	1.258	6
France	1.216	3	1.439	5
United Kingdom	1.140	1	1.188	2
Italy	1.049	1	0.860	0
Malta	0.838	0	1.140	0
Ireland	0.819	0	1.014	2
Czech Rep	0.407	0	0.393	0
Bulgaria	0.289	0	0.267	0
Romania	0.271	0	0.261	0

DIRECT CONSUMPTION SUPPLY CHAIN

Super efficiency scores in 2010 and 2014 – Direct consumption supply chain



INDIRECT CONSUMPTION SUPPLY CHAIN

Descriptive statistics of efficient DMUs – indirect consumption supply chain

	Labour (X1000)	GHG (x1000 ton)	ACG (x1000 ton)	O3PR (x1000 ton)	GVA (x10^6)	Super efficiency score
2010	62 ↓	29,196 ↓	41 ↓	42 ↓	8,724 ↓	1.91 ↓
2014	54	26,350	34	34	8,384	1.71

Descriptive statistics of inefficient DMUs – indirect consumption supply chain

	Labour (X1000)	GHG (x1000 ton)	ACG (x1000 ton)	O3PR (x1000 ton)	GVA (x10^6)	Efficiency score
2010	27 ↑	14,713 ↓	49 ↓	30 ↓	2,468 ↑	0.66 ↓
2014	28	13,107	34	26	2,927	0.65

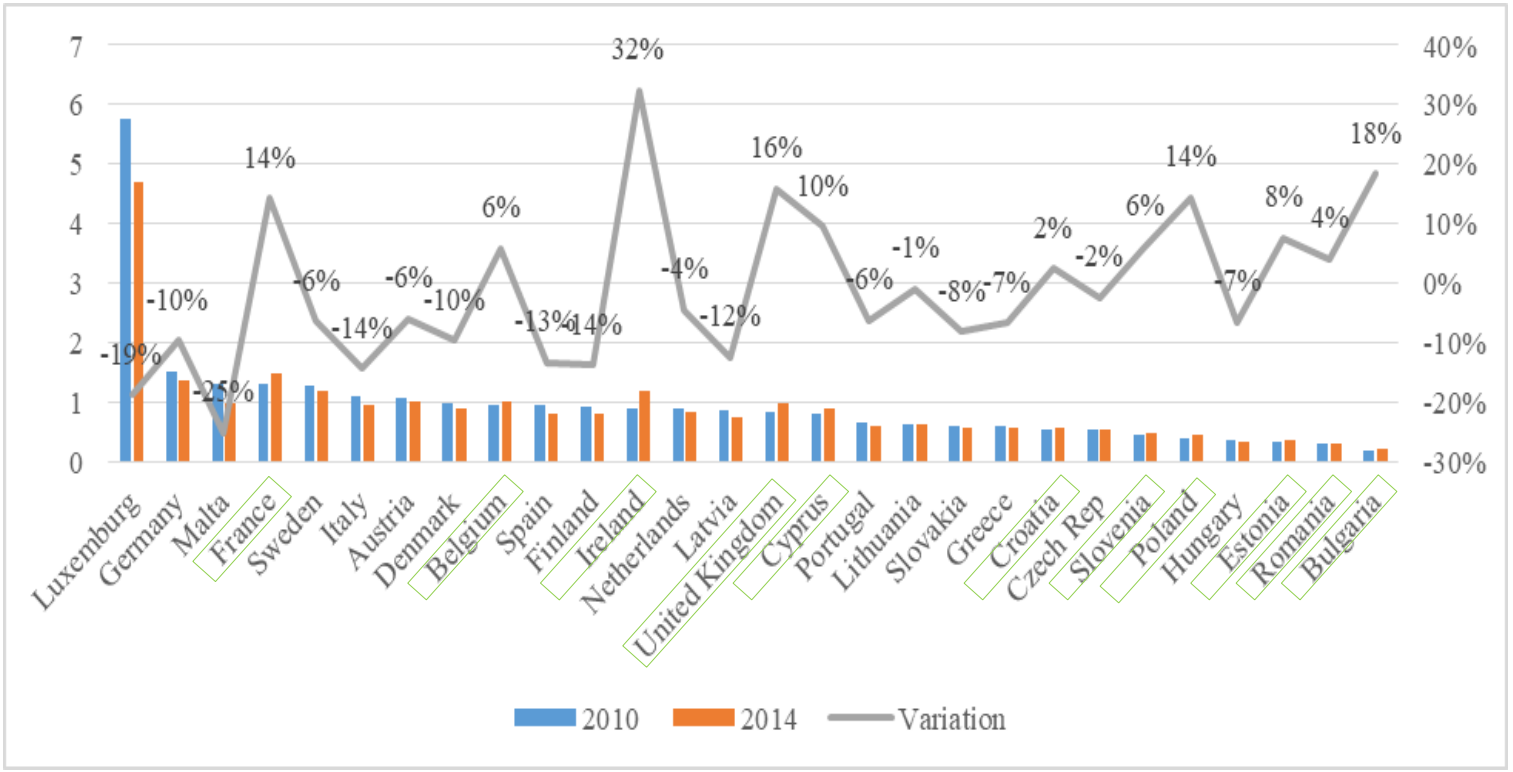
INDIRECT CONSUMPTION SUPPLY CHAIN

Data and efficiency scores obtained in the indirect consumption supply chain in 2010 and 2014

DMU	2010		2014	
	Super-Efficiency Score	Nº of times as Ref.	Super-Efficiency Score	Nº of times as Ref.
Luxemburg	5.775	17	4.695	14
Germany	1.516	3	1.370	1
Malta	1.314	1	0.984	0
France	1.313	2	1.499	5
Sweden	1.276	21	1.195	16
Italy	1.115	0	0.955	0
Austria	1.069	7	1.006	5
Belgium	0.952	0	1.008	0
Ireland	0.891	0	1.179	10
Hungary	0.354	0	0.331	0
Estonia	0.348	0	0.374	0
Romania	0.303	0	0.315	0
Bulgaria	0.194	0	0.229	0

INDIRECT CONSUMPTION SUPPLY CHAIN

Super efficiency scores in 2010 and 2014 – Indirect consumption supply chain



Conclusions

- The average emissions in the direct production and in direct and indirect consumption chains decreased which is consistent with the 31% increase of RES and the 20% reduction of fossil in electricity generation;

- Taking into consideration the direct production chain and the direct and indirect consumption supply chains as a whole:

  - Countries that increased their efficiency scores: France, Ireland, the United Kingdom and Belgium;

  - The efficient countries across all chains, both in 2010 and 2014: France, Luxemburg, Germany and Sweden.

- The countries who invested more in renewable energy deployment efficiently, progressively replacing fossil fuel generation, increased their potential in terms of eco-efficiency by reducing the emissions and stimulating the growth of value added.

LIMITATIONS:

- Lack of comparability of our results with other studies;
- The absence of more updated data for the IO tables.

FUTURE WORK:

- Analysis of the evolution of the eco-efficiency of the electricity sector in the several EU countries to the present date and to compare it with our findings;

- Evaluate which countries have best adapted to the needs of decreasing their inputs and increasing outputs and which policies had responsibility in this evolution.