A proposal for assessing wind power systems in Europe

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3rd AIEE ENERGY SYMPOSIUM
10-12 December, 2018 - Milan - Bocconi University

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Motivation

- The efficiency performance of electric utilities has been a central topic of research.
- Wind Power (WP) was responsible for the generation of 336 TWh in 2017, being responsible for about 11.6% of the EU's electricity demand.
- Since WP systems are currently prospering in the EU, becoming one of the most important electricity power generators, the evaluation of their efficiency should be a major concern.

Motivation

- The novelty of this work is threefold:
  - use of the generalized directional distance function approach to obtain the comprehensive efficiency assessment of WP systems in 17 EU countries;
  - selection of inputs and outputs through panel models;
  - couple both energy and non-energy inputs and outputs in efficiency assessment.

Methods

- **DEA – The generalized directional distance function approach**

- Radial models disregard slacks and the input (output)-oriented models only address the input (output) efficiency;

- This measure allows obtaining the same information provided by the SBM model as long as the directional vectors for inputs and outputs are considered to be equal to the corresponding input and output vectors.

- We have considered a non-radial non-oriented model based on the generalized directional distance function approach, since it can provide a comprehensive efficiency assessment.

Methods

- **DEA – The generalized directional distance function approach**

$$\max \beta_o^R = max\ (w_y(\sum_r \varpi_y^r \alpha_o^r) + w_x(\sum_i \varpi_x^i \zeta_o^i)),$$

$$\text{s.t.} \sum_{j=1}^n \lambda_j y_{rj} \geq y_{ro} + \alpha_o^r g_{yr},$$

$$\sum_{j=1}^n \lambda_j x_{ij} \leq x_{io} - \zeta_o^i g_{xi},$$

$$\sum_{j=1}^n \lambda_j = 1,\ \lambda_j \geq 0\ (\forall_j),$$

Methods

- **DEA – The generalized directional distance function approach**

- It allows for the classification of efficient DMUs.

- The super-efficiency model considers that the efficiency scores of the inefficient DMUs are kept unaffected and the efficiency scores of the efficient DMUs are bigger than 1.

Methods

- **DEA – The generalized directional distance function approach**

Finally, the reference set of the inefficient DMU_o is obtained by solving the following LP problem, considering that α_o^{r*} , ζ_o^{i*} and α_o^* are obtained in the optimal solution to:

$\max \sum_r s_r^{c+} + \sum_i s_i^{c-}$,

s.t. $\sum_{j=1}^n \lambda_j y_{rj} - s_r^{c+} = y_{ro} + \alpha_o^{r*} g_{yr}$,

$\sum_{j=1}^n \lambda_j x_{ij} + s_i^{c-} = x_{io} - \zeta_o^{i*} g_{xi}$,

$\sum_{j=1}^n \lambda_j = 1$, $\lambda_j \geq 0$ $(\forall_j)$,

$s_r^{c+} \geq 0$ $(\forall_r)$, $s_i^{c-} \geq 0$ $(\forall_i)$.

Let $(\alpha_o^{r*}, \zeta_o^{i*}, \alpha_o^*, s_r^{c+*}, s_i^{c-*}, \lambda_j^*)$ be the optimal solution to this problem. Consider the reference set of the inefficient DMU_o as follows:

$E_o = \{ j: \lambda_j^* > 0, j=1, \ldots, n\}$.

The point of the efficient frontier which can be viewed as a target DMU for the WRDDM-inefficient DMU_o is given by:

$(\hat{\boldsymbol{x}}_o, \hat{\boldsymbol{y}}_o) = (\sum_{j \epsilon E_o} \lambda_j^* \boldsymbol{x}_j, \sum_{j \epsilon E_o} \lambda_j^* \boldsymbol{y}_j)$.

Methods

•Selection of inputs/outputs

- One of DEA's drawbacks is that it does not provide a means to select the inputs and outputs that should be considered for the assessment of each DMU.
- However, the efficiency score attained for each DMU is highly dependent on this selection procedure.
- In our case, the inputs and outputs considered were evaluated through parametric and non-parametric panel models.

Methods

•Selection of inputs/outputs

- We started by treating the turnover of every DMU as a dependent variable, and the number of employees, the power capacity and power generation as independent variables.

- The use of non-parametric panel models can help us find which items have an impact on turnover, and classify inputs and outputs easily according to the type of influence of each item on the DMU’s turnover.

Methods

Panel model estimation results

Pooling
Model

turnover ~ employment + generation + capacity

Balanced Panel: n=7, T=17, N=119

	βi	*p*
constant	582.194443	0.014901 *
employment	0.115580	2.158e-09 ***
generation	2.289693	0.003366 **
capacity	-0.440122	0.004711 **

Total Sum of Squares: 1163300000

Residual Sum of Squares: 460330000

R-Squared: 0.60428

Adj. R-Squared: 0.59396

F-statistic: 58.5376 on 3 and 115 DF, p-value: < 2.22e-16

Significance: *** <0.001; ** <0.01; * <0.05

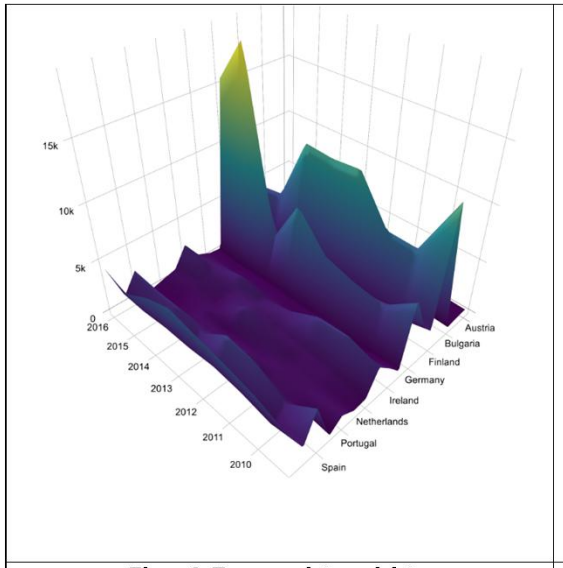


Figure 1. Turnover plot – real data

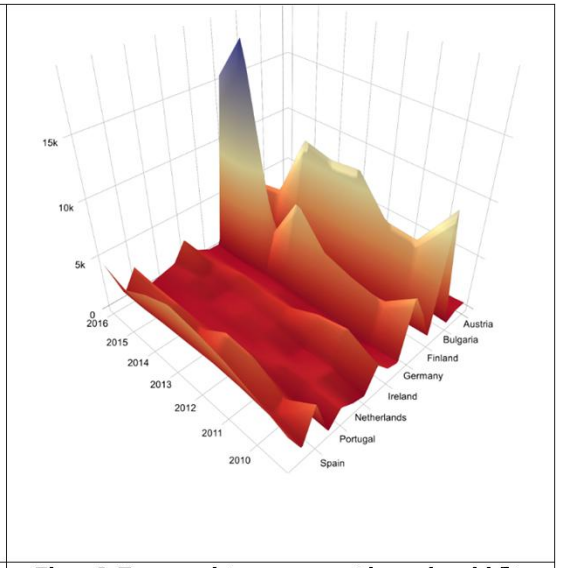


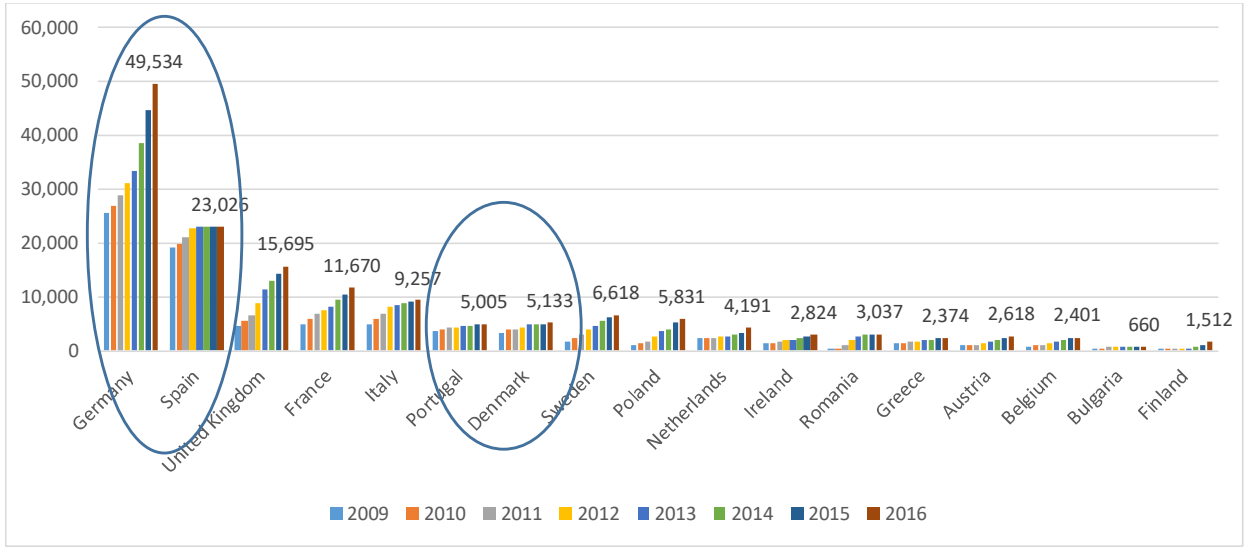
Figure 2. Turnover plot – non-parametric panel model fit

- **Selection of inputs/outputs**

- This led to the choice of both energy and non-energy inputs in the analysis, i.e. the total WP **generation capacity** (in megawatts: MW) and the **number of employees** (in number of persons).

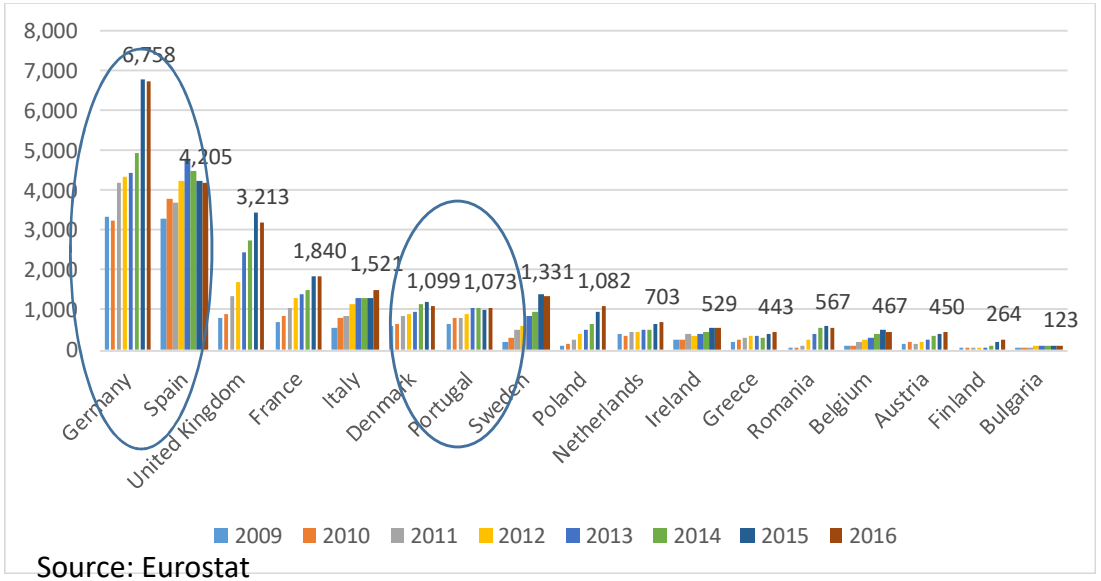
- In the case of energy outputs, the net **WP electricity generation** (in thousand tonnes of oil equivalent: TOE), while for the non-energy outputs the **turnover** (in million Euros: M€) was used.

Data



Source: BP statistical review

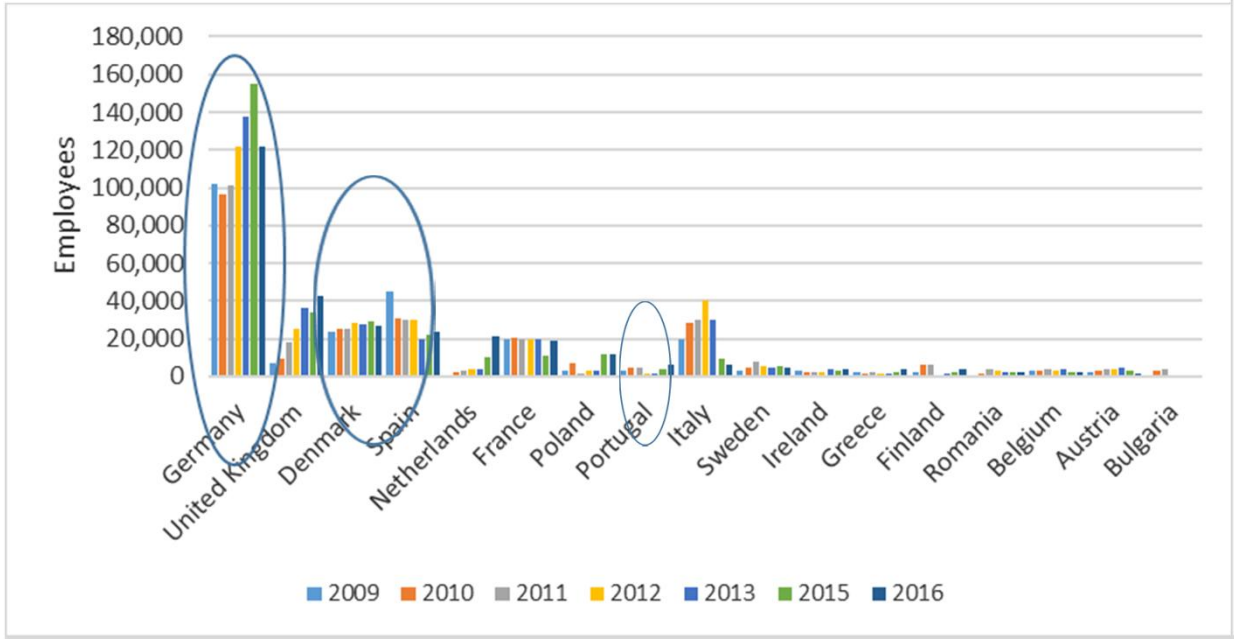
WP Installed capacity in 17 EU countries (MW)



Source: Eurostat

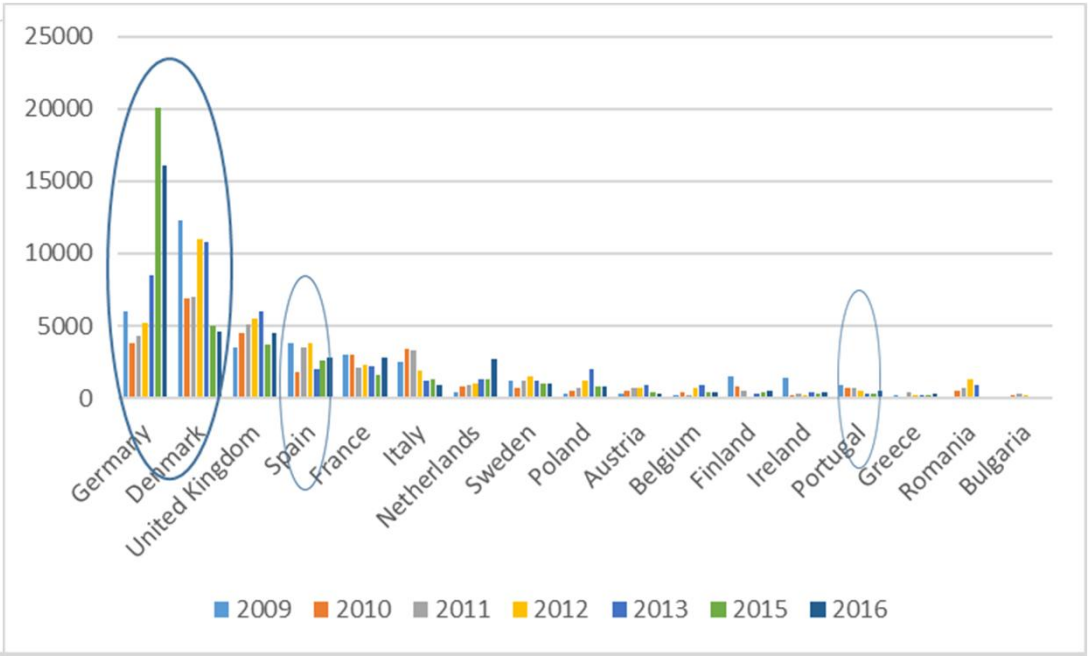
WP generation in 17 EU countries (10^3 toe)

Data



Source: EurObserv'ER

Employment (number of persons)



Source: EurObserv'ER

Turnover (M€)

Results

Overall efficiency scores per year

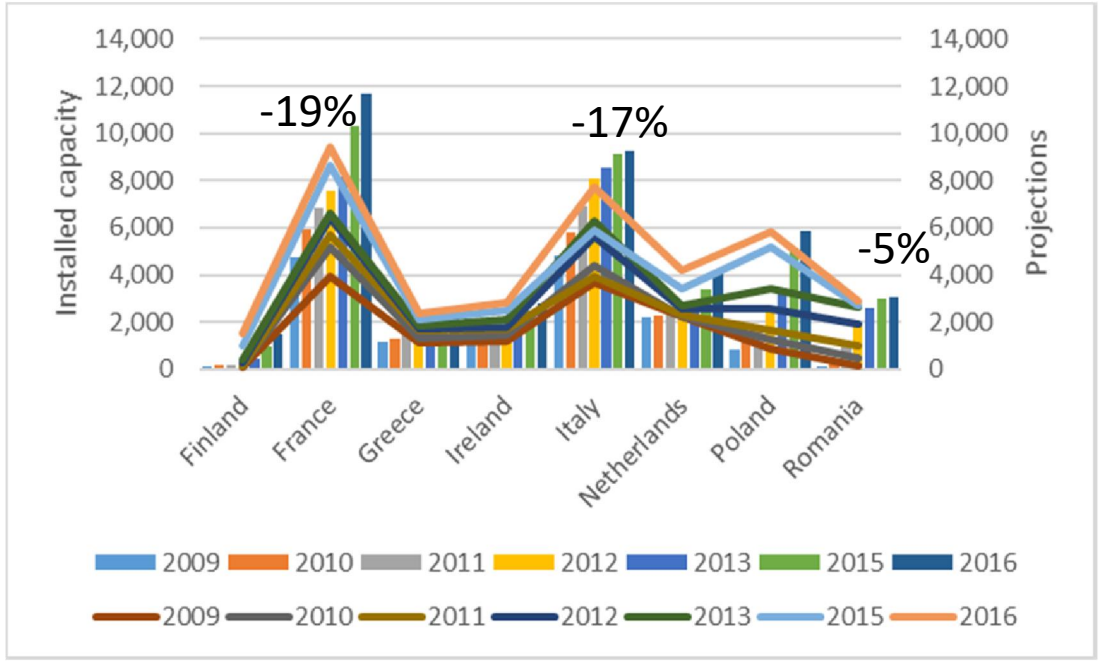
	2009			2010			2011			2012			2013			2015			2016		
DMU	**Nº of times considered as Reference**	**Efficiency Score**	**Rank**	**Nº of times considered as Reference**	**Efficiency Score**	**Rank**	**Nº of times considered as Reference**	**Efficiency Score**	**Rank**	**Nº of times considered as Reference**	**Efficiency Score**	**Rank**	**Nº of times considered as Reference**	**Efficiency Score**	**Rank**	**Nº of times considered as Reference**	**Efficiency Score**	**Rank**	**Nº of times considered as Reference**	**Efficiency Score**	**Rank**
AT	0	0.05	13	2	1.00	11	2	1.01	11	0	0.68	13	0	0.68	13	0	0.86	12	1	1.01	8
BE	0	-0.61	16	0	0.54	16	0	0.48	17	0	0.82	12	0	0.86	11	7	1.03	7	6	1.03	6
BG	0	-0.89	17	1	1.01	10	2	1.10	5	7	1.24	2	8	2.25	1	6	2.12	1	7	2.20	1
DK	7	1.19	4	7	1.14	5	12	1.13	3	12	1.21	3	11	1.19	2	8	1.19	3	12	1.13	3
FI	9	1.46	2	3	1.54	1	3	1.66	1	2	1.35	1	1	1.19	2	0	0.99	10	0	0.94	10
FR	0	0.39	11	0	0.70	12	0	0.49	16	0	0.48	15	0	0.40	14	0	0.93	11	0	0.93	11
DE	1	1.06	7	1	1.05	8	2	1.07	7	2	1.04	6	1	1.14	6	2	1.31	2	1	1.30	2
GR	0	-0.25	14	5	1.08	6	0	0.75	13	0	0.53	14	0	0.31	15	0	0.64	15	0	0.67	15
IE	4	1.03	9	0	0.69	13	4	1.06	8	0	0.28	16	0	0.30	16	3	1.00	8	0	0.79	14
IT	0	0.14	12	0	0.67	14	0	0.58	15	0	-0.23	17	0	-0.93	17	0	0.82	14	0	0.90	12
NL	6	1.23	3	2	1.02	9	2	1.03	9	0	0.87	10	0	0.89	9	0	0.86	12	0	0.84	13
PL	0	-0.53	15	0	0.30	17	6	1.20	2	6	1.01	8	9	1.10	7	0	0.52	16	0	0.57	16
PT	2	1.04	8	4	1.07	7	1	1.02	10	11	1.17	4	11	1.15	5	1	1.00	8	2	1.01	8
RO	2	3.65	1	6	1.39	2	1	1.00	12	1	1.02	7	0	0.88	10	0	0.43	17	0	0.43	17
SP	2	1.11	5	3	1.15	3	4	1.13	3	5	1.15	5	4	1.17	4	4	1.10	5	4	1.11	4
SE	0	0.81	10	0	0.57	15	0	0.75	13	0	0.87	10	0	0.83	12	8	1.12	4	9	1.10	5
UK	9	1.09	6	8	1.15	3	7	1.08	6	0	0.89	9	1	1.05	8	5	1.05	6	2	1.03	6

Results

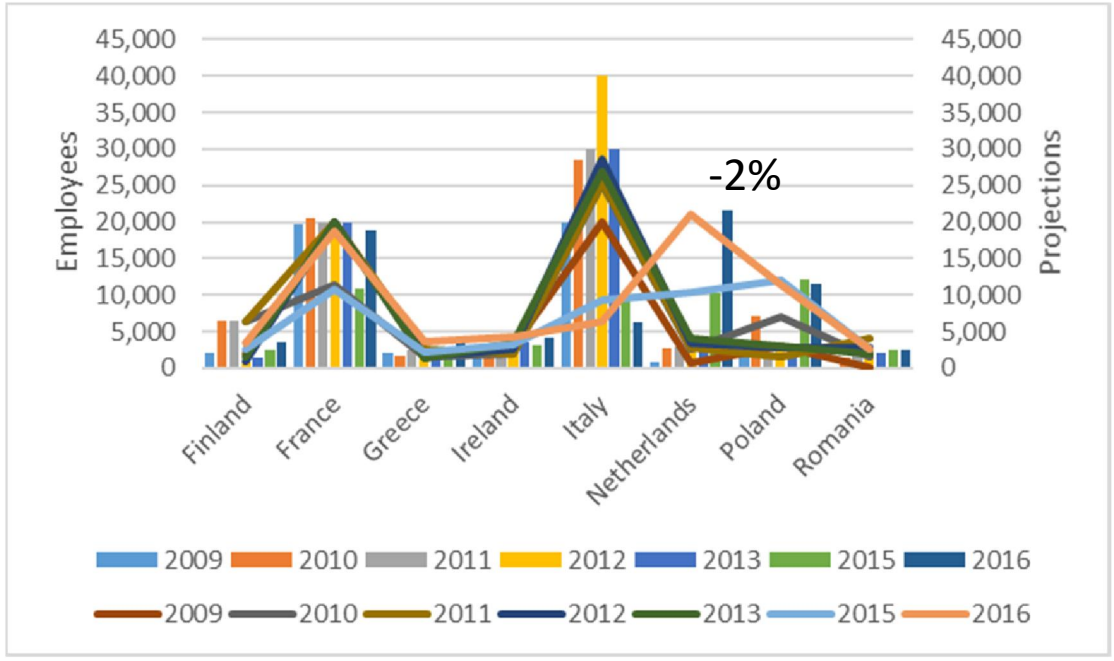
- Countries always classified as efficient in the time horizon herein considered: Denmark, Portugal, Germany and Spain.
- Denmark: due to its geographical characteristics, propitiate weather conditions of wind farm locations, low variable and fixed costs, Danish operators have low O&M costs when contrasted with other countries' operators.
- Portugal: adoption of a FiT mechanism in this country and WP operators are mainly owned by multinational companies and major economic groups.
- Germany and Spain are two major players of WP systems in the EU.

Results

- In 2016, eight countries should perform several adjustments on their inputs and outputs in order to become efficient regarding their peers.



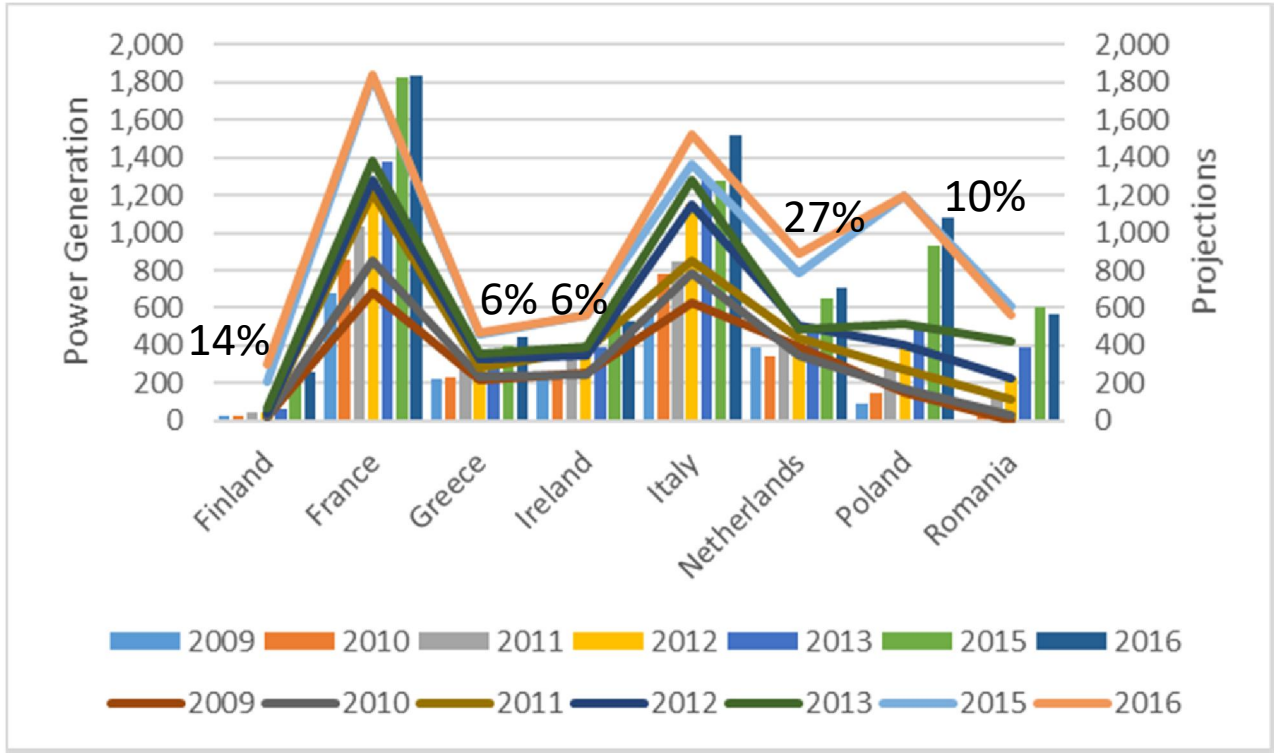
Real installed capacity vs projection



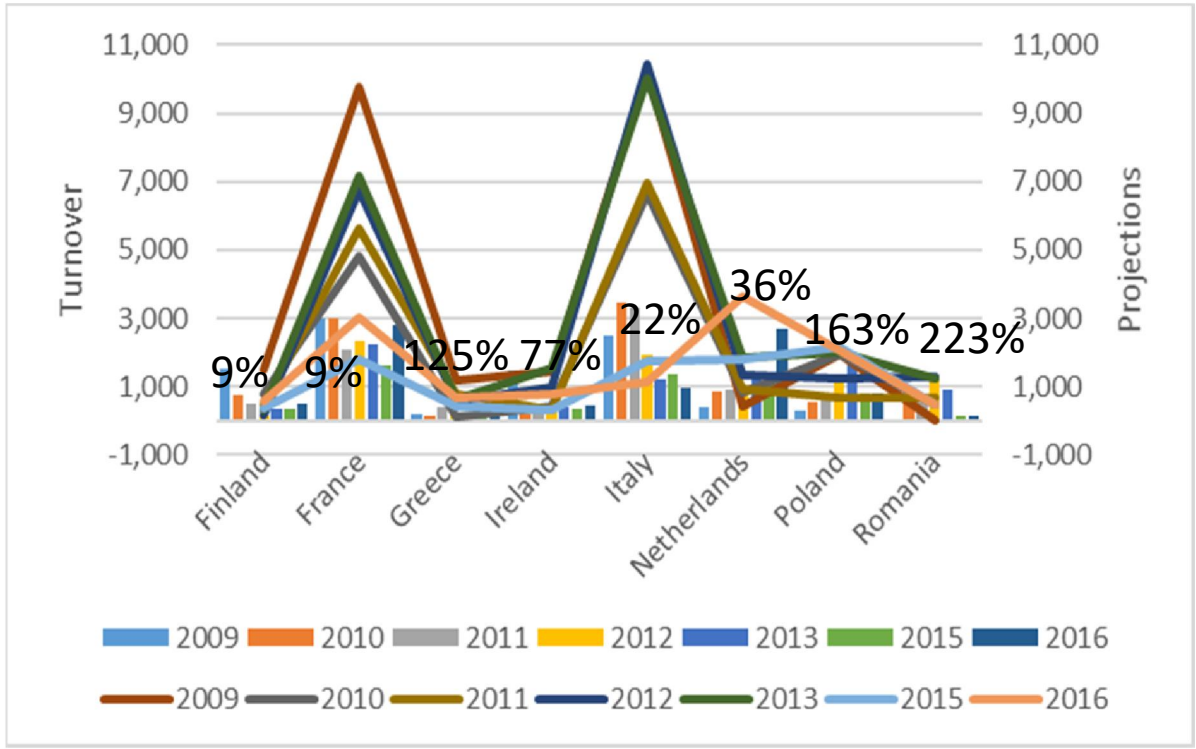
Real employment vs projection

Results

- In 2016, eight countries should perform several adjustments on their inputs and outputs in order to become efficient regarding their peers.



Real power generation vs projection of non-efficient countries



Real turnover vs projection of non-efficient countries

Results

- The countries more frequently classified as non-efficient are France, Greece and Italy.
- In the case of France, the overcapacity of WP systems is the main driver of bad performance;
- In the other countries, the continuous change and adaption of the support schemes might have a significant role on these results.
- Overall, it can be ascertained that countries which are more often classified as WP efficient adopted FiT at an early stage of WP deployment.
- Finally, it can be concluded that, except for 2012 and 2013, the majority of the countries were operating their WP systems efficiently.

Summary and Conclusions

- This paper provided an assessment of WP systems in 17 EU countries.
- Energy and non-energy input and output factors were used in this analysis.
- In general, it can be established that except from 2012 and 2013, the period particularly impacted with the economic crisis, the majority of these countries had efficient WP systems in this period of analysis.
- Nevertheless, with the regulatory framework of some countries still undergoing a downturn, it might be expected that in the future the WP efficiency statuses of some of these countries might cease to exist.
- Future work: try to encompass other type of inputs and outputs in WP assessment, namely the average annual wind speed (as a non-controllable input); the average rated power by country (as a controllable input) and the bad outputs regarding the manufacturing stage of the additional installed capacity in each year by means of the IO approach/LCA approach.