NON-PEER-REVIEWED PAPER

Flexible industrial processes: a valuable tool to accommodate big scale variable renewables. Assessment of additional wind power integration by industrial demand side management

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Abstract

The progressive penetration of variable renewables in the European electricity landscape requires, together with the upgrade of transmission networks, the development of flexibility means to match generation and demand. Given the limited capacity to store electricity at big scale, a massive deployment of demand side response will be required in the years to come. Industry accounts for one third of the EU electricity consumption. Deploying its DSM potential would unlock significant amounts of valuable balancing resources.

The development of industrial DSM requires a proper economic valorization of the flexibility. A number of avenues can be considered: integration of on-site wind power, integration of off-site wind power, adapting demand to electricity price signals, offering balancing capacity to Transmission System Operators (TSOs) … In this study the first option is analysed (integration of on-site wind power).

Findings: eleven flexible industrial processes could accommodate in Europe, under economic conditions, 68 GW of additional wind capacity, delivering 176 TWh/year of electricity, out of which 2/3 would be self-consumed on-site.

Introduction

The progressive penetration of variable renewables in the European electricity landscape requires, together with the upgrade of transmission networks, the development of flexibility means to match generation and demand. Given the limited capacity to store electricity at big scale, a massive deployment of demand side response will be required in the years to come. Industry accounts for one third of the EU electricity consumption. Deploying its DSM potential would unlock significant amounts of valuable balancing resources. Initiated and financed by the European Copper Institute (ECI), the German company SYNLIFT Systems GmbH analyzed the technical and economic potential for powering ten selected industrial processes by wind energy at EU-27 scale at 2020 time horizon (project phase I finished in 12/2012).

This paper presents the methodology used, the data available and the results of phase I (accomplished).

Any interested party is invited to join the consortium being currently developed to implement a demonstration project (industrial site, energy management system provider, electricity market and regulation expert …).

Project Aim

The aim is to assess the potential for on-site wind generation and self-consumption, under economic conditions, for a selection of electricity intensive industrial processes at EU-27 scale and at 2020 time horizon.

General Methodology

The general approach consists in assessing the local wind condition and the electricity prices for each concrete location of the main industrial plants (of the selected process) in EU-27. The levelized cost of wind energy is then compared to the average electricity price for the industrial sector in each country. In the cases where the price differential is positive, an opportunity for self-consumption exists. The price difference is first used to pay-back for the required investments to exploit the flexibility of the process (either product storage, manufacturing capacity or energy management systems), then to make an economic profit.

Grid electricity prices for industry have been clustered into 4 categories.

The price difference between the levelized cost of wind energy and the grid electricity prices has been clustered into 10 categories.

Electricity Prices

Grid electricity prices for industry (>2 GWh/year) are obtained from Enerdata database for the period 2006 to 2010.

Next, it is applied an annual increase of 2 % to grid electricity prices, starting in 2010 and ending in 2020.

Finally, the resulting prices at 2020 horizon are clustered into four classes (G I to G IV).

Most of the countries grid tariffs belong to the lower classes G I (0.07 EUR/kWh ≤ 0.11 EUR/kWh) and II (0.11 EUR/kWh ≤ 0.15 EUR/kWh). The two higher classes contain the following countries: Germany and Malta in G III (0.15 EUR/kWh ≤ 0.19 EUR/kWh); Denmark and Cyprus in G IV (0.19 EUR/kWh ≤ 0.23 EUR/kWh).

Wind Energy Generation Cost

The wind energy generation cost is calculated based on wind speeds at 80 m above the ground [2].

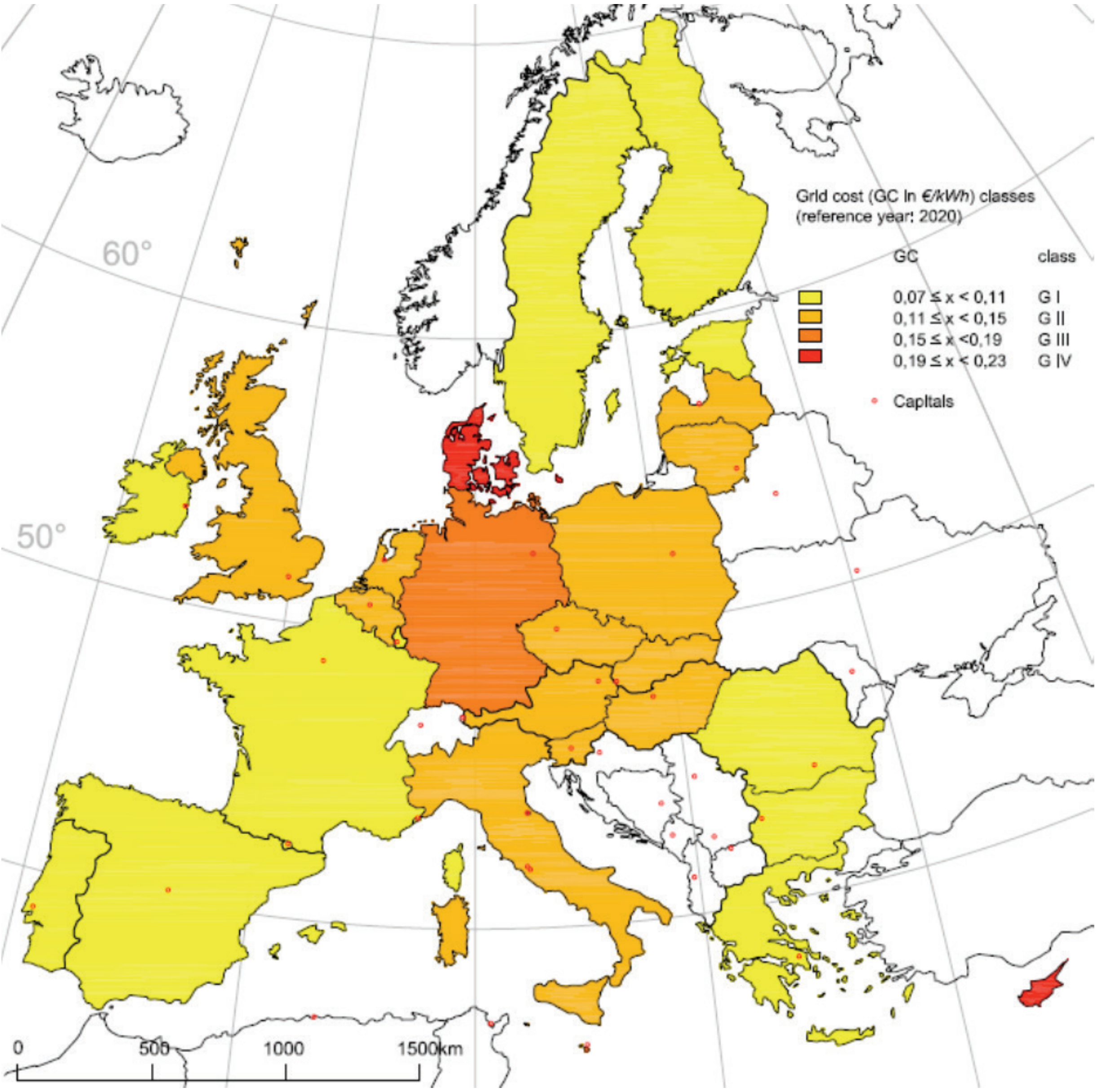

Figure 1. Grid cost.

Four classes of levelized cost of wind energy are then defined and represented in a map (Figure 2).

Differential Costs

The levelized cost of wind energy is then compared to the grid electricity prices, country by country. Ten price differential categories are defined (Figure 3).

The maps shows how Denmark, Germany, UK and Cyprus offer a significant price differential between the levelized cost of wind energy and the grid electricity prices. In these countries the opportunity to valorize the industrial flexibility is very high. Other countries can also have local interesting opportunities, but are not considered at this level of analysis.

Relevant Industrial Processes

Eleven industrial applications are selected based on the following criteria:

- Electricity has a high share in the total cost of the manufactured product.
- The sector represents a relevant share of the electricity consumption in EU.
- The process is suitable for load management [6].

The following processes were selected: chlorine-alkali-electrolyses by membrane technique (chlor), air separation, aluminum production (alu), copper production, mechanical pulp production, paper recycling, electro steel production (e-steel),

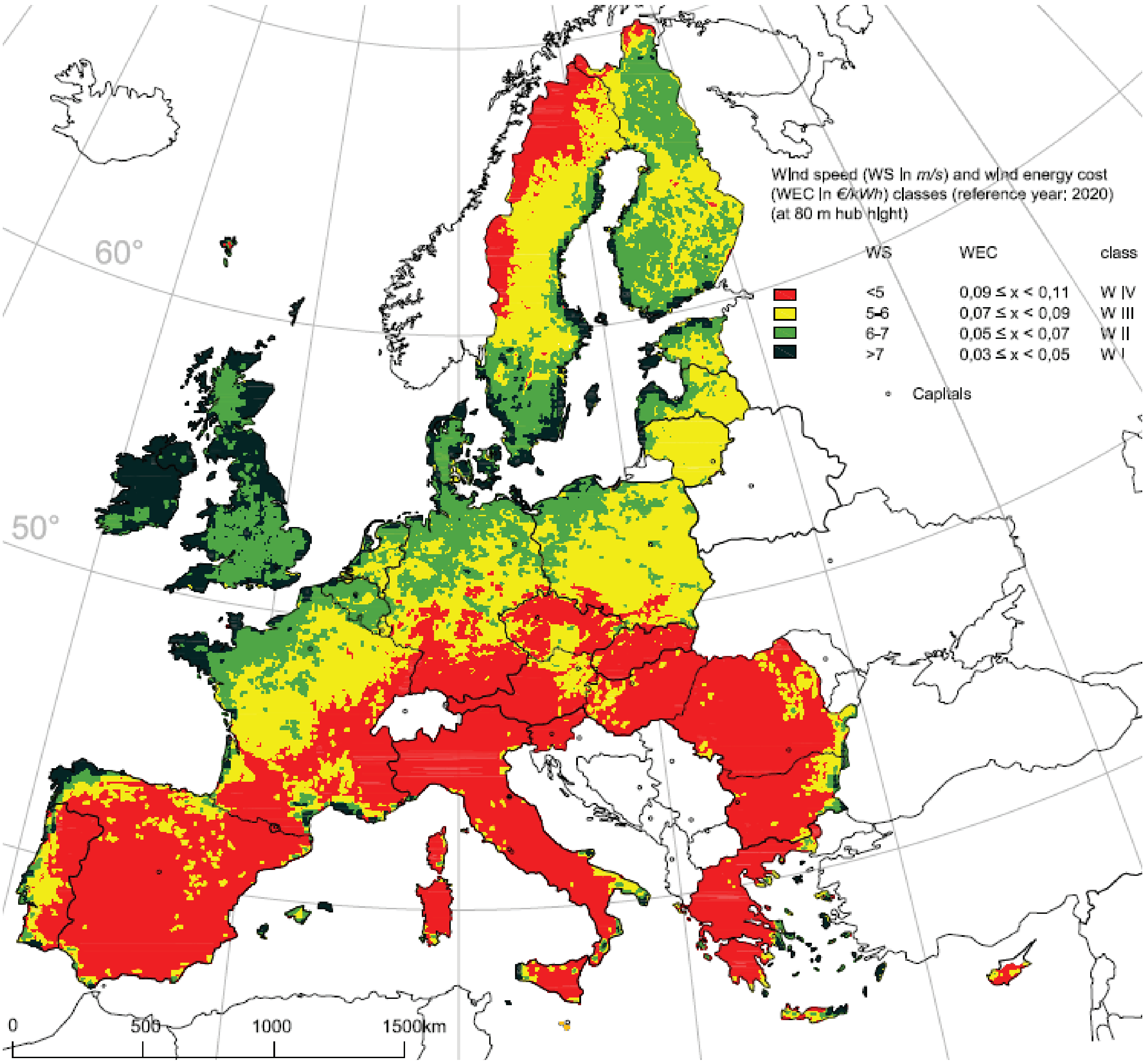

Figure 2. Wind speed and wind energy cost classes.

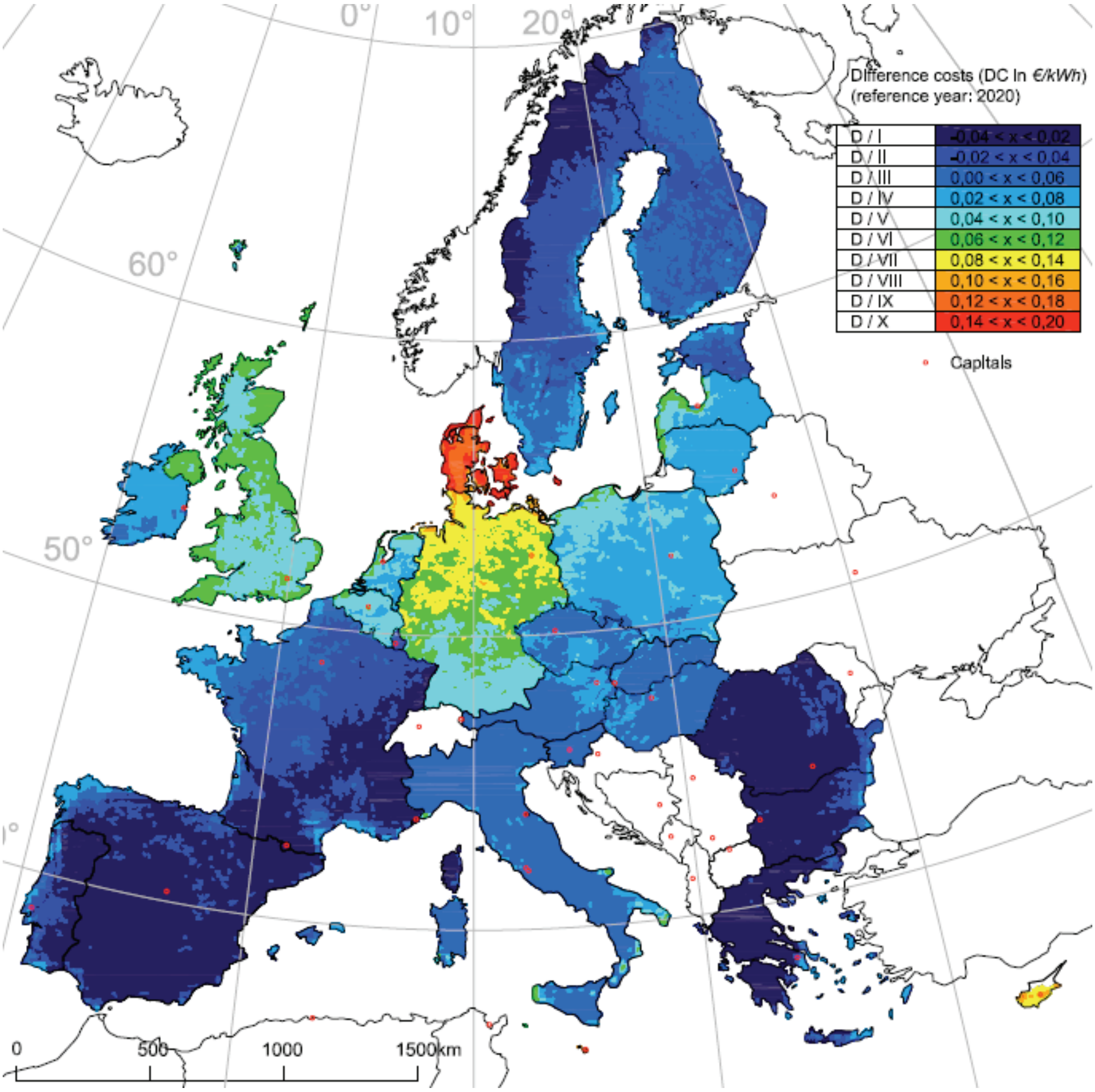

Figure 3. Difference costs.

cement industry, cold storage, seawater desalination and zinc die casting.

These sectors consume 220 TWh per year, around 20 % of the total electrical consumption of EU industry sector.

Technical and Economic Potential

The **technical suitability** of a process for demand side management is assessed according to the following criteria: time behaviour, capacity range, synchronism, power gradient, activation effort and development state.

Following such assessment, chlorine-alkali and desalination are clustered as having a high technical potential, aluminium and cold storage medium potential and e-steel low potential.

As for the **economic potential**, it has been considered the fact that some investments will be required in the process (additional process capacity, additional storage, energy management systems …). Only investments leading to a payback period shorter than 10 years are considered. Based on this, the minimum price difference between wind and grid costs to make the project profitable is as follows in Table 2.

The price difference is given in a range. The lower value is required to achieve a wind penetration of 70 % (electricity with wind origin/total electricity consumed), while the higher value corresponds to a wind penetration of 90 %.

Wind Power Potential Assessment

Table 3 represents the potential for application, under economic conditions, of on-site wind energy power for self-consumption purposes.

The 10 sectors selected represent an annual consumption of 220 TWh. Excluding those sites where there is no economic potential for application of the concept, the target industrial locations represent a consumption of 180 TWh/year. Two thirds of this consumption could be provided by self-produced wind

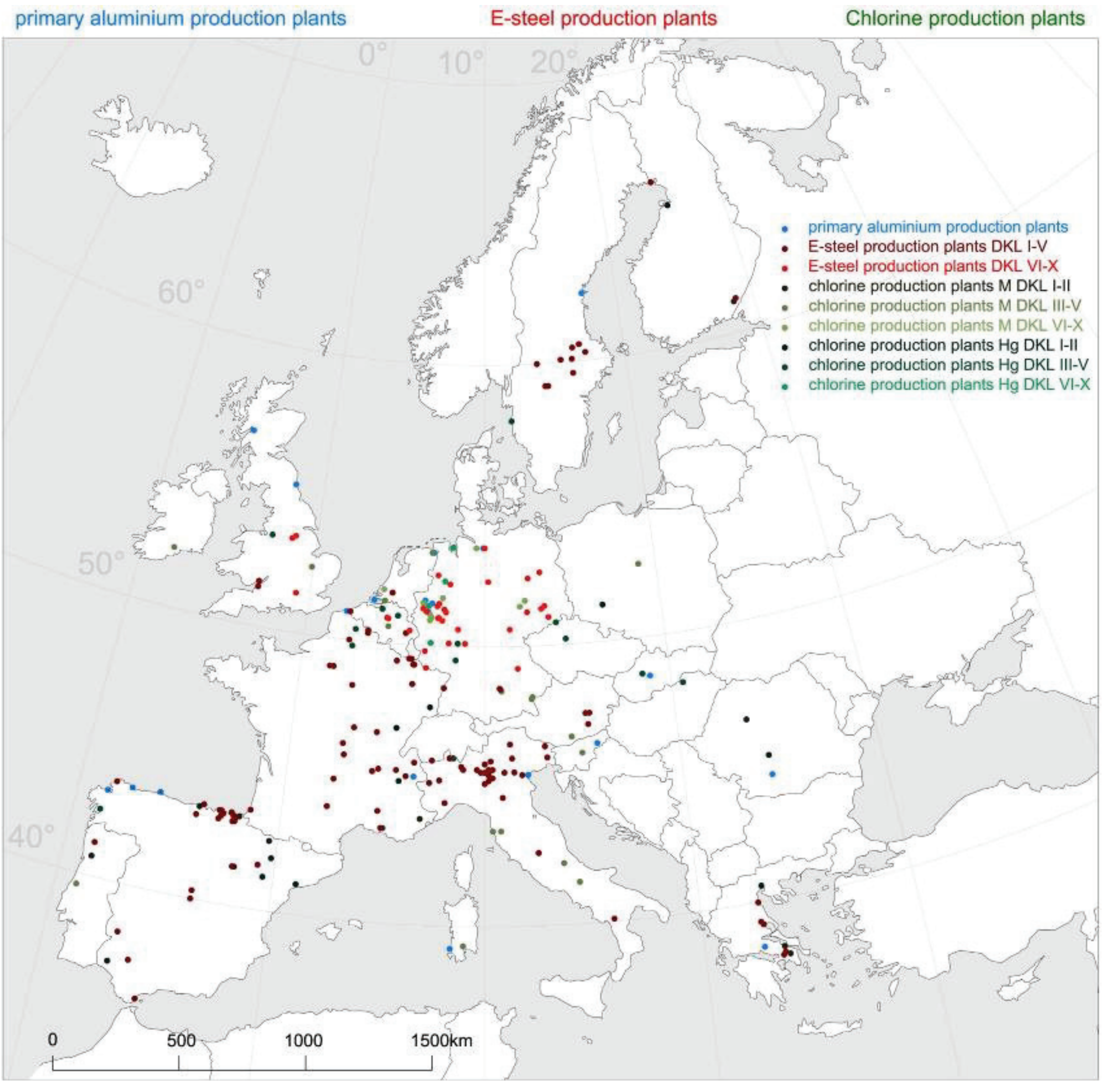

Figure 4. Primary aluminium, e-steel and chlorine production plants.

Table 1. The technical suitability of a process for demand side management.

Application	Time behaviour	Capacity Range		Synchrony	Power Gradient		Activation effort	Development state	Category
		Overload	Part load		Short time scale	Long time scale			
Chlorine-Alkali	Continuous	High	High	Yes	Low	High	Low	Proven	High
Aluminium	Continuous	(Medium)	(Medium)	Yes	High	(Medium)	Low	Conceptual	Medium
E-Steel making	Batch	Low	(High)	No (material)	(Medium)	High	(Medium)	Conceptual	Low
Cold storage	Continuous/Batch	(Medium)	(Medium)	Yes	High	Medium	Low	Conceptual	Medium
Desalination	Continuous	High	High	Yes	Medium	High	Low	Demo	High

Table 2. The minimum price difference between wind and grid costs to make the project profitable.

Process	Price difference (€/kWh)
Chlorine – Alkali	0.025 to 0.082
E – Steel	0.089 to 0.200
Desalination	0.040 to 0.122

Table 3. The potential for application of on-site wind energy power for self-consumption purposes.

Process	Economic potential for on-site wind power	Sector consumption	Excluded from economic on-site wind	Net sector with on-site wind potential	Wind generation	Wind self-consumption	Self-consumption ratio	Wind generation exported to grid
	GW	GWh/year	GWh/year	GWh/year	GWh/year	GWh/year		GWh/year
Chlor	10	31447	5401	26046	26000	21798	84%	4202
E-Steel	10	32485	5564	26921	26000	16610	62%	9390
Alu	13	41739	8520	33219	33800	20783	63%	13017
Desalination	2	5399	985	4414	5200	3238	73%	1962
Cold Storage	9	29504	5381	24123	23400	16845	70%	6555
Air Separation	5	17471	3186	14285	13000	8941	63%	4059
Mechanical pulping	6	18545	3382	15163	15600	9491	63%	6109
Paper recycling	6	18545	3382	15163	15600	9492	63%	6108
Cement production	6	19263	3513	15750	15600	9858	63%	5742
Cu and Zinc Production	1	4481	817	3664	2600	2293	63%	307
TOTAL	**68**	**218879**	**40131**	**178748**	**176800**	**119349**	**67%**	**57451**

power (the remaining 60 TWh need to be imported from the grid). About 58 GWh/year of excess wind power is required to be exported to the grid (and valorized at the levelized cost of wind energy in each case).

The total additional wind power that could be accommodated reaches 68 GW, which is as much as two thirds of the total wind power installed in Europe.

Assumptions for electricity prices and sensitivity analysis

Electricity prices for industry (in the category of 2 to 20 GWh/year annual consumption) in 2010 have been used for its extrapolation at 2020 horizon considering an annual increase of 2 % per year. A number of considerations can be made:

- The prices used include the grid access term (fixed term), the energy term and taxes. In the event of on-site generation and self-consumption, the energy term would be saved, however one could wonder whether the taxes and the fixed term could be saved as well.
- The consumer category in the range of 2–20 GWh/year can run short for big industrial facilities. One could consider having a look to bigger industrial categories (20–70 GWh for instance).
- The annual price increase has been set at 2 %/year in a 10 years period. Another approach could be based on the extrapolation of the rates observed in the recent past years.

Taking all these factors into account, alternative scenarii are defined, for which the fixed term and taxes are not avoided costs and bigger consumer categories are considered. Also, the annual price increase is assumed to follow the same pattern as in the previous years. Let's see the results in such cases picking up a sample country such as Germany (Tables 4–7).

Out of three alternative scenarii, two of them present equal or reinforced conclusions as the base scenario.

The conclusions of this analysis would be valid provided the price of electricity is equal or higher than €0,168/kWh at 2020 horizon (**Base Scenario**).

In **Scenario 1**, a bigger consumer class has been considered (which would facilitate lower prices for energy) and only the electricity costs without taxes have been considered. In exchange, the conservative 2 %/year price increase has been replaced by a more realistic 7,1 % which is the average value observed in the period 2004–2012. In such case, the resulting electricity price at 2020 horizon is €0,180/kWh, which is even higher than the price considered in the Base Scenario, reinforcing the conclusions of the study.

Scenario 2 is the most challenging scenario, as only the estimated cost of energy without taxes is considered. It is assumed here that the electricity bill is split in two: the fixed term and the energy term. The fixed term has been allocated with 15 % of the bill, while the energy term is assumed to represent 85 % of the bill. In this case, still considering a 7,1 % price increase from 2012 to 2020, the electricity price to consider reaches €0,153/kWh, €0,015/kWh below the price assumed in the Base Scenario. This 10 % deviation could have an impact on the results, but in principle quite limited as the difference is small.

Scenario 3 is probably the most realistic one. This corresponds to a situation where the fixed term remains the same (the power contracted with the grid needs to be maintained at its original level to cope with wind fluctuations) and only the energy term can be saved. It is assumed that the energy not consumed doesn't pay taxes. In such case, the estimated cost of energy at 2020 horizon would be as high as €0,210/kWh, significantly higher than the €0,168/kWh of the Base Scenario, reinforcing then the conclusions of the study.

Price data have been extracted from Enerdata database (http://www.enerdata.net/).

Conclusion and Ongoing Activities

The development of industrial DSM requires a proper economic valorization of the flexibility. A number of avenues can be considered: integration of on-site wind power, integration of off-site wind power, adapting demand to electricity price signals, offering balancing capacity to Transmission System Operators (TSOs) … In this study the first option is analysed (integration of on-site wind power).

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Table 4. Germany Base Scenario.

Consumer category	2–20 GWh/year
Price	full fixed term + energy term + taxes
Initial year	2010
Price at initial year (€/kWh)	0,138
Annual price increase	2,0 %
Final year	2020
Price at final year (€/kWh)	0,168

Table 5. Germany Scenario 1.

Consumer category	20–70 GWh/year
Price	fixed term + energy term (no taxes)
Initial year	2012
Price at initial year (€/kWh)	0,104
Annual price increase	7,1 %
Final year	2020
Price at final year (€/kWh)	0,180

Table 6. Germany Scenario 2.

Consumer category	20–70 GWh/year
Price	estimated energy term (no fixed term, no taxes)
Initial year	2012
Price at initial year (€/kWh)	0,088
Annual price increase	7,1 %
Final year	2020
Price at final year (€/kWh)	0,153

Table 7. Germany Scenario 3.

Consumer category	20–70 GWh/year
Price	estimated energy term + associated taxes (no fixed term)
Initial year	2012
Price at initial year (€/kWh)	0,122
Annual price increase	7,1 %
Final year	2020
Price at final year (€/kWh)	0,210

Currently the company Synlift Systems is carrying out in-depth assessment of three industrial companies in the chemical, air separation and metal sectors. The objective is to start demonstration projects in 2014 onwards with a consortium as wide as possible. Any interested party is invited to join the initiative (industrial site, energy management system provider, electricity market and regulation expert …).

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