On the Economics of Curtailment of Wind Power plants in the European legislative context

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The Horizon 2020 (H2020) program states all European countries are required to put extra effort in increasing their green energy production. As green energy production is more decentralizedthan energy production based upon fossil fuels, either a network upgrade or a more flexible energy network is required.Within this publication we look into controlled in-feed reduction of windmills as a method to offer flexibility and compare it with the cost of a network upgrade. To do so, we analyze the business cases of both the distribution net owner and the windmill park owner and look into the effect of different compensation methods for curtailing energy. Finally, we look into the current European legislation concerning the curtailment of energy,validate whether this legislation is too narrow and propose a number of changes.

Keywords–Smart grids, energy curtailment

I. THE EFFECT OF H2020 GREEN ENERGY GOALS ON EXISTING ENERGY DISTRUBTION NETWORKS

One of the goals of the Horizon 2020 (H2020) program of the European Commission states 20% of all final energy consumption should originate from renewable energy sources. To reach this goal, all countries of the European Union have received their own specific targets: going from 10% (Malta) all the way up to 49% (Sweden), each increasing their green energy production on average with 10%. In Belgium green energy production should go up from 2.2% to 10.80%[1].

As green energy production – whether it is produced using solar panels, biofuel or windmills – is more decentralized than energy production based upon fossil fuels, the existing electrical grid is put under pressure. Often this requires grid investments or a smarter and more active managed existing distribution grid e.g. using dynamic line rating (DLR), demand side management (DSM)or in-feed reduction of production (curtailment).

Within this publication we propose a model to compare grid investments with long-term curtailment using a number of different compensation schemes and match it with the corresponding European legislation.

The remainder of this paper is structured as follows:In section II an overview of the relevant legislation of a number of European countries is provided. In section III we give a detailed look on the proposed model, including a number of different repayment schemes. Section IV provides a number of case studies using this model after which we compare the results with the regulatory rules found from the European countries..Finally section V summarizes this paper and proposes possible tracks for future work.

II. OVERVIEW OF LEGISLATION OF EUROPEAN COUNTRIES

Table 1: Overview of legislation on curtailment and corresponding compensation of a number of European countries

Country	*Allowed for*	*Compensation*	*Ref*
Belgium	Security	None	[2]
	Local congestion <2% energy[1]		
France	Security	None	[2]
	Congestion	Unknown	[2]
Germany	Local congestion < 1% energy	95% of Income loss	[3]
	Local congestion > 1% energy	100% of income loos	[3]
	Security	None	[3]
Ireland	Security	None	[4]

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[1] Within the scope of a test project, 2% curtailment is currently allowed however only for a number of windmills and for a limited time

Italy	Local congestion	15% of market price	[5][4]
	Security	None	[5]
Spain	Non-planned curtailment	15% of market price	[6]
	Planned curtailment	0%	[6]
Sweden	Security	0%	[2]
United Kingdom	Security	100%	[7]

III. PROSED MODEL

Changing energy production from a centralized approach to a more distributed approach may lead to localized energy congestion. As a direct result, either the transition to a more flexible network (including techniques such as DSM, energy storage or curtailment) or network upgrades are required. Within this publication, we compare flexibility offered using curtailment with a network upgrade (cable installation).When the in-feed of a windmill is being reduced, curtailed, green energy is not produced[2], in other words the WMPO (windmill park owner) suffers a direct loss.

In order to calculate the effect of curtailment of energy on the business cases of both the WMPO (windmill park owner) and the DNO (distribution net owner), we have looked into the cost of a cable installation, the cost of energy, governmental support and different repayment schemes which compensate lost energy revenues for the WMPO.While this approach does not give a total overview of the business cases of the DNO and the WMPO, all considered costs and profits are directly linked to energy production (and thus curtailment) and do not influence nor are influenced by any other part of each business cases, which makes a case-by-case comparison still most useful.

A. Cable cost

When the energy congestion is solved using a network upgrade, two costs have to be taken into account: an upfront installation cost and a yearly maintenance cost.

$$\text{Cable cost}[€] = \text{length}[m] * \text{cable price}[\frac{€}{m}]$$

$$\text{Maintenance cost (yearly)}[€] = \text{maintenance cost}[\frac{€}{m}] * \text{length}[m]$$

Table 2: Cost parameters for cable cost calculation

Parameter	*Value*
Length	5 km
Cable price	74.65 €/m
Maintenance cost	0.44 €/m

Table 2provides the cost parameter for the considered cable investment. Beside the two aforementioned costs, one additional cost could be considered. When a current is transported through a cable, small net losses occur (due to the internal resistance of the cable) however these are negligible when compared to the total business case.

B. Governmental support

In Europe, different non-interchangeable country-specific markets exist for green certificates (Renewable Energy Certificates (REC) in the USA). In Belgium, green certificates have a fixed size (1MWh) and a fixed price (93 euro at the time of writing[8]). While the price and size of a single certificate is fixed, a variable parameter called the banding factor has been introduced. This parameter is differentdepending on the type of production (solar/wind/…) and the size of the installation. This allows the government to change the support for each category of green energy installations without affecting the price of a single certificate.

$$\#GC = \text{production}[MWh] * \text{bandingfactor}$$

$$\text{income}[€] = \#GC * \text{price}(GC)$$

The banding factor is updated half-yearly and is set (at the time of writing) to 0.681for new on-shore windmills in 2015[9]. An overview of green energy support in Belgium is listed in[10].

Within this model, we suppose the DNOdirectly buys the green certificates from the WMPO at the default price and sells them at the same rate, thus not affecting the business case of the DNO. Whengreen energy is curtailed, that energy has not been produced and logic would dictate no green certificates are awarded, however onecould argue whenever a WMPO should be compensated for the loss of these certificates. Within this model, we suppose that no green certificates are awarded for curtailed energy, however using the repayment schemesin the next paragraphs, it is possible to compensate the WMPO for both lost energy and green certificate revenues.

C. Repayment schemes

Energy which has been curtailed is lost and can obviously not be sold; which means a direct income loss for the WMPO. A repayment scheme defines the compensation the WMPO gets from the DNO for lost energy (and possible lost green certificates). As green energy losses should be minimized, it is important that the repayment scheme yields a real incentive to curtail less energy (curtailing high amounts of energy should be discouraged).In the next paragraphs, a number of compensation schemes are proposed, which are also visualized in Figure 1.

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[2] The exact method used to reducethe in-feed is beyond the scope of this publication.

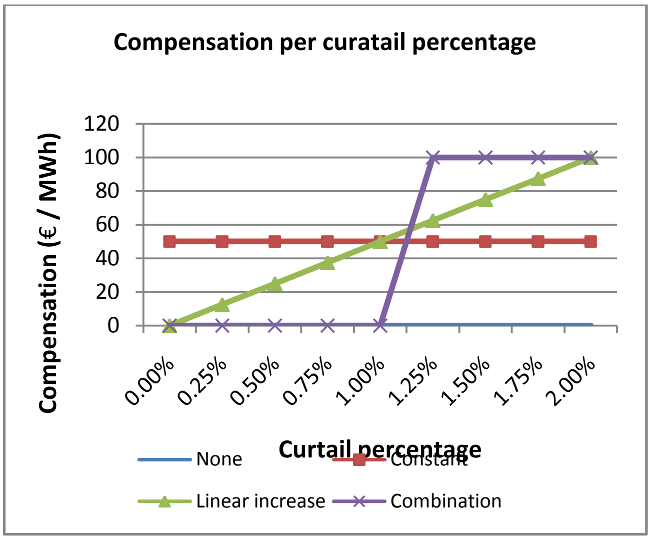

Figure 1: Overview of different curtailment compensation schemes

1) *No compensation*

The first compensation scheme is most basic and offers no compensation for lost energy. This compensation can be used when legislation allows for free curtailment (e.g. for security measures). This compensation scheme is a simplification of the second one.

2) *Constant compensation*

The second compensation scheme offers a constant compensation, in other words every MWh is compensated equally. This seems as the most straightforward scheme; however it does not yield a real incentive to curtail less energy as discussed earlier.

3) *Linear / exponential increase*

The third compensation schemes allows for an increasing compensation, either linear or exponential. Using this approach, every percentage curtailed gets more expensive, in other words, this scheme actively incentivizesto curtail only small amounts of energy.

4) *Combination of schemes*

The final possibility combines two or more of the previous schemes. This allows the model to easily reflect all regulatory decisions as discussed in section II,e.g. first 1% curtailment is for free, afterwards a constant compensation. Any combinations of the schemes are possible, which allows the steer the market, which is discussed in section IV.

D. Energy cost

The last component considered in the model is the energy price. As energy is curtailed, the WMPO loses direct income. Depending on the region, different pricing schemes can be assumed (e.g. day-ahead price or fixed price).

$$\text{income}[€] = \text{production}[\text{MWh}] * \text{price}(t)\left[\frac{\text{MWh}}{€}\right]$$

Within this study we assumed a fixed price of € 50 per MWh, which is the average of consumer energy prices of the last year, derived from open data retrieved from [11].

IV. CASE STUDY

A. Comparison of different compensation schemes for lost energy with no wind variation

In this first case we compare the cost of a network upgrade (cable installation)with the cost of curtailing energy using a number of different repayment schemes. For this model we have not taken into account any variations of the wind speed (see case B). For this case we consider three compensation schedules:

- A constant scheme at € 50 per MWh, which reflects the energy price.
- A constant scheme at € 143 per MWh (50+93), which reflects the energy price and the governmental support for 1 MWh.
- A linear increasing repayment schedule, which values the first percentage at € 50 per MWh and increases linearly to € 500(at 10%).

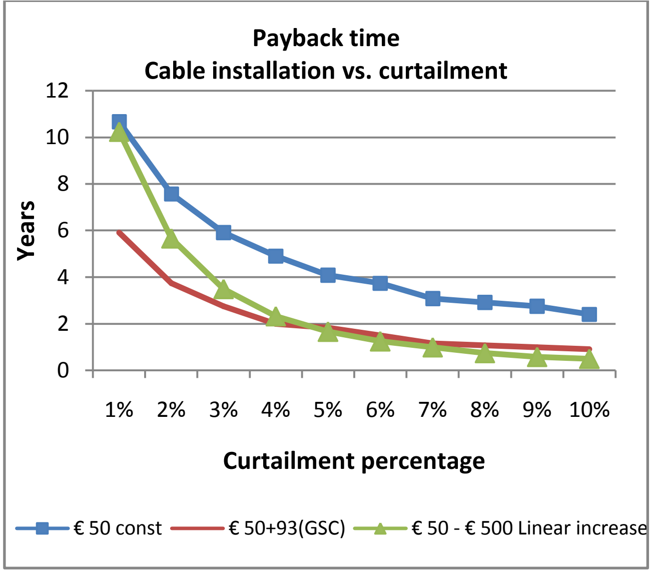

Figure 2: Payback time for a net upgrade compared with curtailment for three different compensation schemes.

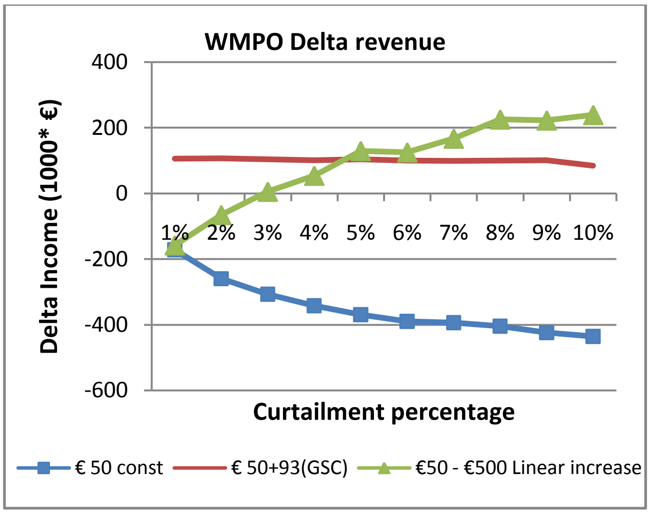

Figure 3: Income difference for the WMPO depending on percentage curtailment and the chosen compensation scheme.

From Figure 2 we can deduct that for small energy congestion problems, up to 5%, curtailment can be used as a financial viable solution for multiple years. In a fastchanging energy network, in which new windmills are added each year, curtailing a small percentage of energy for just a few years, before even larger upgrades are required, could thus offer a cost-effective solution for the DNO. When we look into the changed income for the WMPO (Figure 3), we can see that, depending on the chosen compensation scheme, curtailment can offer additional revenues.

B. *Looking into the curtailment window*

In Belgium, curtailing 2% energy on a yearly basis is currently allowed only within a test project. This 2% is a fixed percentage per year, in other words it is not averaged for a number of years.In Figure 4 the average yearly wind speed, measured in Ukkel (Belgium),is given for the last 20 years[12].From this figure, we can easily deduct that the spread on this values is 0.5m/s (3.1 to 3.6), and the standard deviation is 0.17m/s, or adeviation of nearly 5%, which is clearly higher than the 2% allowed curtailment. In order words, when dimensioning the network for the average wind speed (while keeping in mind 2% energy can be curtailed on a yearly basis), energy congestion might still occur depending whenever it is a good or bad wind year[3].
The same exercise has been repeated for longer spans of time (1960-2015), for which similar findings were found.

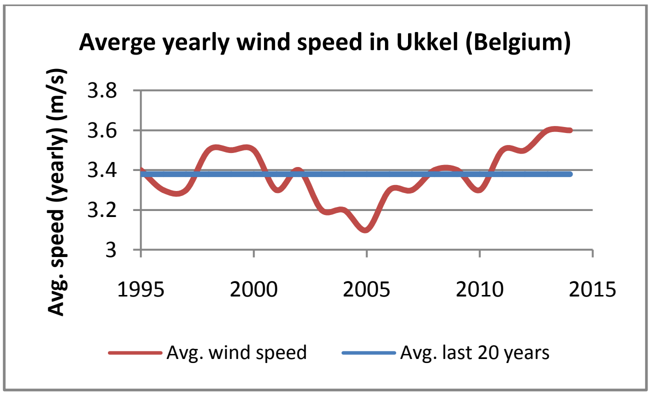

Figure 4: Average wind speed in Ukkel (Belgium) during the last 20 years.

Next, we have looked into the size of the timing horizon for these deviations to be canceled out by. We have considered time spans of 3, 6, 9 and 12 years.

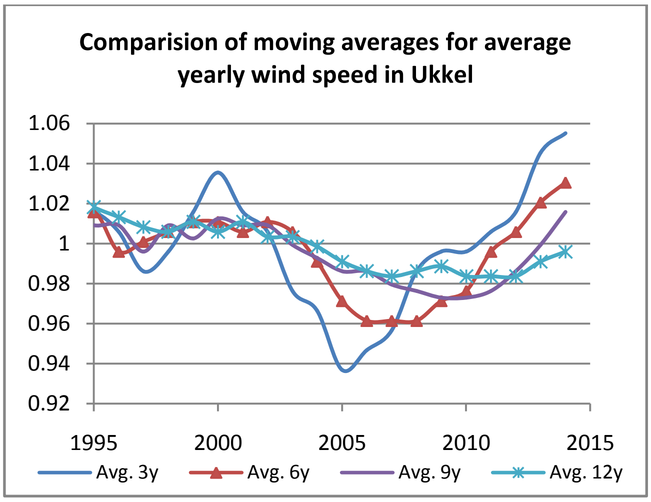

Figure 5: Comparison of moving averages for average yearly wind speed in Ukkel

Figure 5 shows the average wind speed averaged on 3, 6, 9 and 12 years. Only the moving averages of 9 and 12 years manage to keep the deviation under 2% all the time; the moving average of 6 years manages to cancel out most of the variations, while 3 years clearly is too short. Based on these results, one could suggest altering the current legislationto allowcurtailment of 2% energy, averaged out for at least 6 to 9 years.

V. CONCLUSION

In paragraph II we have looked into the legislation of different European countries concerning the curtailment of energy. Some of these countries allow the curtailment of energy (e.g. Germany, up to 1% of the income), while other countries only allow curtailment for security reasons and not for local congestion.
In a first use case, we have compared a network upgrade (cable installation) with flexibility offered using curtailment. From this case we can learn thatlow curtailment percentagesmight be a financial viable solution for the DNO for multiple years, while extra revenues are generated for the WMPO. In other words, allowing curtailment for local congestion could make sense from an economical point of view, ifthe chosen compensation scheme is beneficial for both the DNO and the WMPO.
In a second use case, we have looked into the annual variations in wind speed and how this affects the application of current legislation. In this case we have learned that the formulation of the current legislation (of countries like Belgium and Germany)should be altered: instead of setting a curtailment limit per year, a limit averaged over at least 6 to 9 years should be used to take into account these variations in the wind speeds.

This study has proposed some initial results of how flexibility can be offered using curtailment in an existing energy network and how this flexibility is affected by current legislation. This studycould be extended in a number of fashions:

- So far in this study we have supposed the DNO makes all decision (the WMPO simply decides if it

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[3] Hereby we make the assumption that total energy output per year is directly linked to the average wind speed.

wants to install a windmill or not). By including the cost to connect the windmill to the energy network, the DNO could apply a location-based pricing strategy. This approach would allow the DNO to make areas where the network currently has overcapacity to be more interesting (lower connection cost), while areas where congestion may occur would be less interesting (higher connection cost) to install a new windmill. Using a game-theoretical approach, the optimal mix of connection cost and the matching curtailment compensation scheme could be found.

- Storing curtailed energy in any kind of system (e.g. a battery), so curtailed energy is no longer lost and can be sold later on either the normal or the imbalance market may result in an extra income either for the WMPO, the DNO or an additional third party.
- Within this study we currently discarded any possible wear costs originating from curtailing energy, which may not be negligible.This study could be extended to include any wear and tear to the windmill in relation to the total time curtailed and/or the method used to curtail. This way, shorter life span of the wind mill or higher maintenance costs could be included in the business case of the WMPO.

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