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**COMMUNICATION**

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# The consequences of time correlations for PPA on the renewable/ RFNBO status of hydrogen produced in chlor-alkali

To enable the use of renewable hydrogen from chlor-alkali production there must be a supportive regulatory framework. Current discussions on RFNBO- classified hydrogen indicate that short time periods between production will be applied meaning that the use of hydrogen from chlor-alkali will not be possible, a monthly correlation is the is the minimum. Additionally, current technological limitations in battery storage capacity and/or efficient hydrogen conversion and storage, as well as legal limitations on storage of chlorine gas, complicate this further.

## Introduction

Chlor-alkali plants typically produce three products; chlorine, caustic soda/potash and hydrogen. These are made simultaneously by the electrolysis of brine (common salt dissolved in water). Electricity is therefore an important 'raw material' of this energy-intensive industry.

According to the latest legislative proposals, to ensure that any hydrogen produced is classified as renewable (RFNBO), the production unit has to be connected to a (new) renewable electricity production unit. This can most likely be done via a direct connection to a wind or solar park or by arranging the renewable electricity via a Power Purchase Agreement (PPA). The rules for matching a PPA between the time of production of the renewable electricity and the time of use of the renewable electricity are currently under discussion.

There are significant consequences of some of the above mentioned time correlations that are under discussion though. We will exemplify those in the following chapters by considering a chlor-alkali unit that produces 200,000 tonnes of chlorine and 64 million $Nm^3$ $H_2$ per year. This hypothetical plant has an hourly operating rate of between 86% and 100% (a standard pattern for this type of industry). and is supplied by renewable electricity from an off-shore wind and solar park in Belgium.

## The production of Belgian off-shore wind

Figure 1 shows the load curve of the off-shore wind and solar in Belgium in 2021. These data are taken from the Entso-e transparency platform (https://transparency.entsoe.eu/). The overall performance in 2021 was, for the off-shore wind, a load factor of 33% and for solar 14%. The installed off-shore wind capacity was 2.2 GW and for solar 3.8 GW.

**Euro Chlor**
Rue Belliard 40, Box 15, B-1040 Brussels
mpa@cefic.be
EU Transparency Register n° 64879142323-90

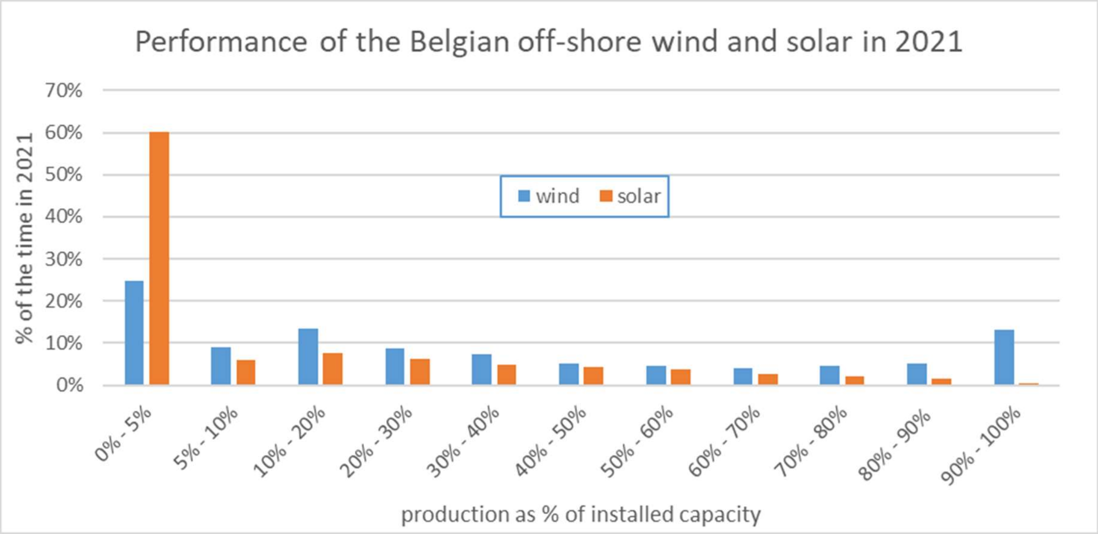

*Figure 1: Load curve of Belgian off-shore wind and solar in 2021*

## Belgium’s rooftop solar and on-shore wind potential

EnergyVille/VITO has estimated that Belgium has a technical potential for renewable energy generation of 118 GW from photovoltaics (PV) on roofs and on-shore wind installations.[1] ‘Creativity’ will be needed to utilise this immense capacity, all within a regulatory framework that supports this.

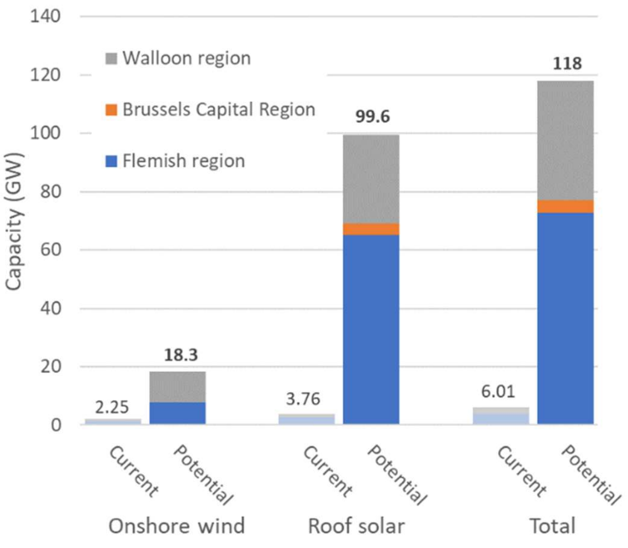

*Figure 2: Installed capacity (2018) and technical potential per technology and regions in Belgium. (source: EnergyVille/VITO)*

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[1] See : How much renewable electricity can be generated within the Belgian Borders (Dynamic Energy Atlas) EnergyVille/Vito

## The chlor-alkali production unit

For calculation purposes, the hypothetical chlor-alkali production unit of 200,000 tonnes of chlorine per year (64 million $Nm^3$ hydrogen or 5,700 tonnes of $H_2$) operates between 86% and 100%. This unit has an electricity demand of 64 MW when it is on 100% load. The yearly demand is 520,000 MWh. This 200,000 tonnes per year represents the average size of a chlor-alkali unit in Europe. The number of sites, with their capacity ranges, is listed below:

| | |
|---|---|
| • Number of installations with a capacity < 100,000 tonnes/year | 29 |
| • Number of installation with a capacity between 100,000 and 300,000 tonnes/year | 21 |
| • Number of installation with a capacity of > 300,000 tonnes/year | 12 |

If this hypothetical site were to be connected to a wind park, this park would require an installed capacity of 167.5 MW (or 7.6% of the installed off-shore wind capacity in Belgium in 2021). This requires a wind park containing approximately 12 wind turbines of the largest size currently available for off-shore wind (14 MW per wind turbine) requiring an area of approximately 75 $km^2$. That is to say, such a wind park would deliver, over 1 year, the same amount of electricity as required by the chlor-alkali production unit. However on an *hourly* basis, the wind park's production and the demand of the chlor-alkali unit will rarely align as can be seen in Figure 3 and Figure 4 below.

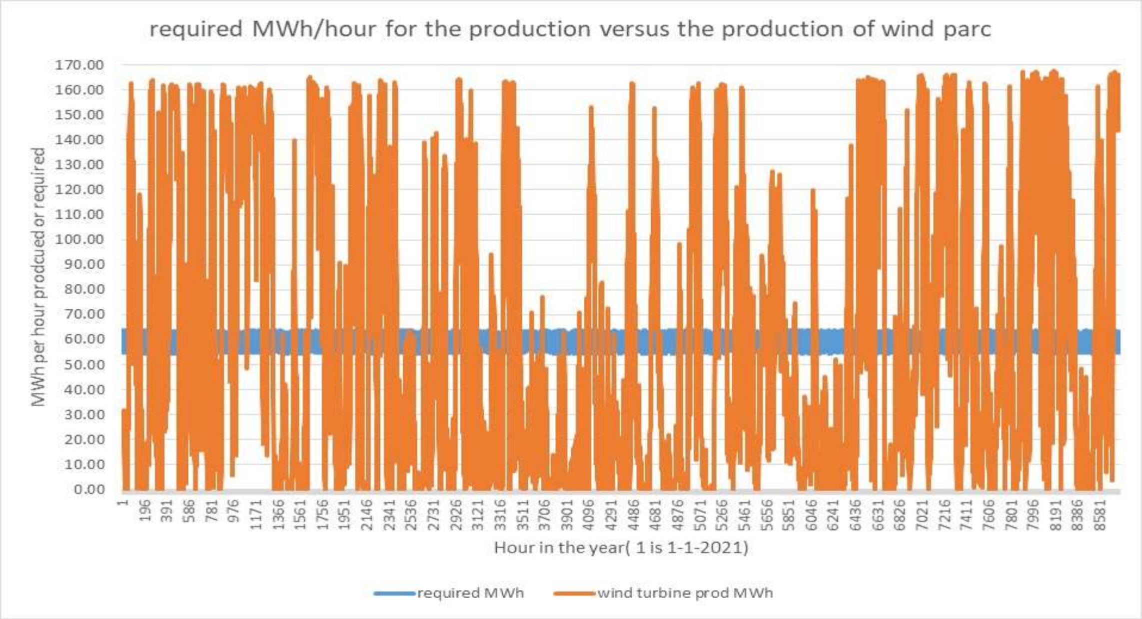

*Figure 3: The relationship between the production of the wind park (per hour) and the demand of the electrolysis unit on an hourly basis*

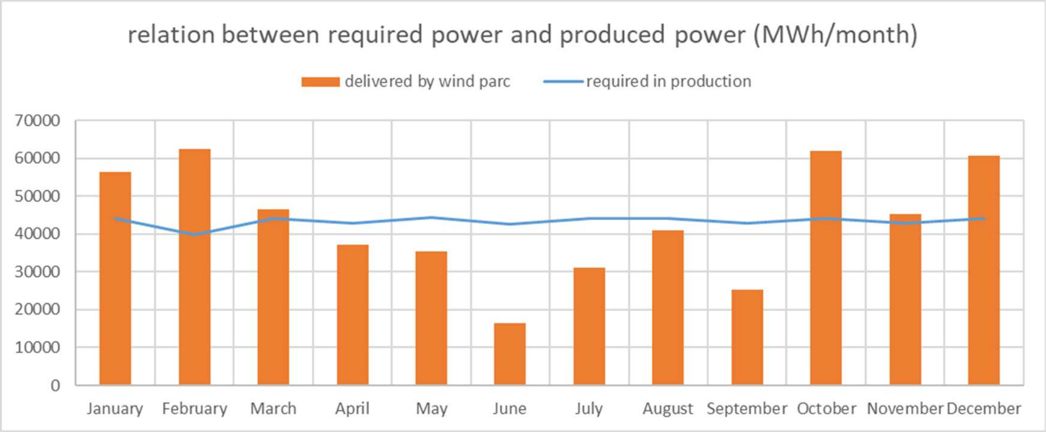

*Figure 4: The relationship between the production of the wind park and the demand of the electrolysis unit on a monthly basis*

Similar calculations can be done should this installation only run on solar energy (an even more complex scenario). In this case, a solar park with a maximum capacity of 421 MW (or 11% of the installed solar capacity in Belgium in 2021[2]) would be required and this would produce enough electricity in one year to deliver the amount required by the production unit. A solar park with this capacity requires an area of approximately 4.3 km$^2$, equivalent to 600 football fields. However the imbalance in this case is even greater than that of the wind park example above (figure 5).

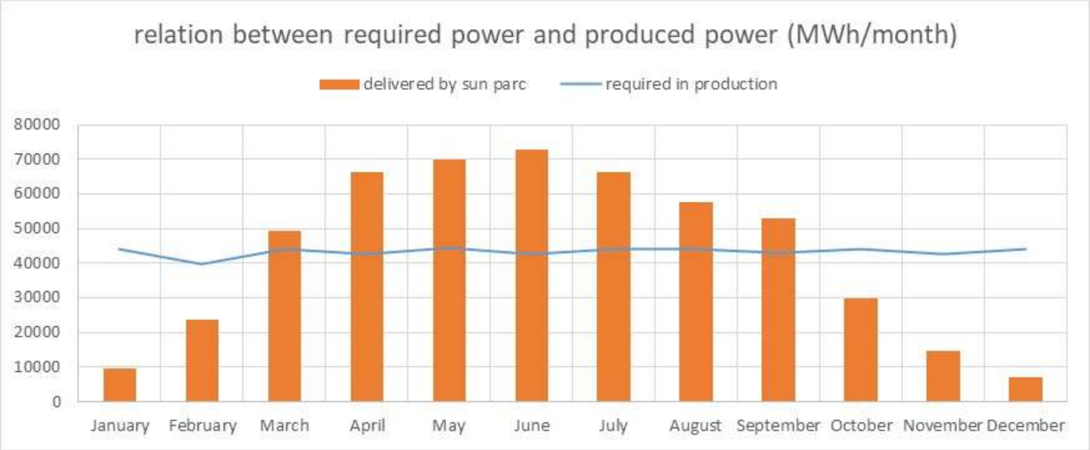

*Figure 5: The relationship between the production of the solar park and the demand of the electrolysis unit on a monthly basis*

## The effect of time correlations for the renewable production

### Consequences of an hourly correlation

The renewable/ RFNBO production discussions need to consider the relationship between the *production* and *use* of the renewable electricity. In the examples above (assuming the production can only be considered as renewable when the produced renewable electricity is consumed in the same hour), only 58% of the produced wind electricity is used in the same hour as it is produced. This means that only 58% (301,600 MWh) of the produced hydrogen could be considered as renewable. The other 42% (218,400 MWh) of the wind electricity produced would have to be used by others.

To overcome this "time-gap", batteries could be used to store any excess for when the electricity production of any renewable sources is less than the demand. The storage of this remaining 42% would require a battery capacity of approximately 90,000 MWh. (see figure 6). The amount of electricity coming from batteries is 218,400 MWh. To get this energy in and out of the battery, a loss of approximately 10% has to be considered. So to get this 218,400 MWh out of the battery pack one has to put in 242,700 MWh. This difference of 24,400 MWh increases the power consumption of the hypothetical electrolysis plant by approximately 4.6%.

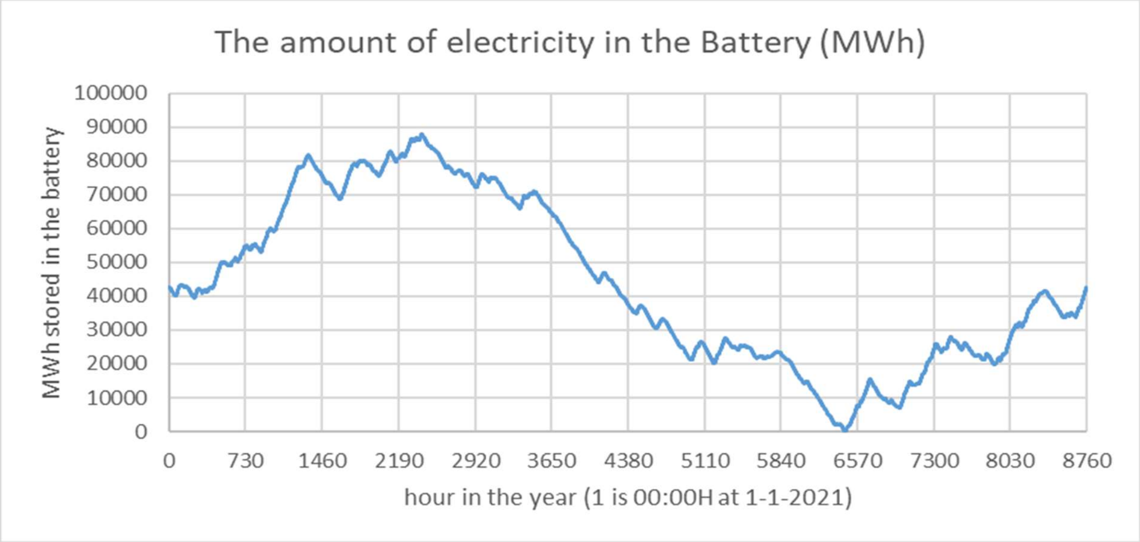

*Figure 6: The amount of electricity stored in the battery pack to balance between overproduction wind and the need of the electrolysis unit.*

For use in chlor-alkali, such a battery pack is unrealistic at present. To give an idea of the scale of this, the battery pack of a high-end electric car is approximately 100 kWh meaning that the chlor-alkali unit would require a battery pack containing the batteries of approximately 900,000 cars.

Another option would be to store the electricity as hydrogen and then convert it back to electricity when renewable production is less than the demand. This approach suffers from considerable losses in efficiency though. For example, when one MWh of electricity is converted into hydrogen, stored (under pressure) and then reconverted back to electricity one would receive approximately 0.28 MWh. In our hypothetical chlor-alkali plant, the stored (and reconverted) hydrogen would need to deliver around

218,400 MWh (equivalent to approximately 12,850 tonnes of hydrogen). To produce this amount of hydrogen in the first place would require approximately 770,800 MWh. As such, the overall energy consumption of the unit would rise to 1,072,400 MWh or 2.06 times the normal demand.

Another option could be to create more flexibility in the chlorine production unit itself and store the production in order to maintain supply for downstream users. In order to completely match customer demand, on an hourly basis, the production level of our example unit would have to be increased by a factor of 2.6. It would also require 16,500 tonnes of chlorine and 465 tonnes of hydrogen to be stored (equivalent to 1 month of production). From a permitting standpoint, such storage would not be allowed as modern storage conditions are only allowed for a single day. Such a situation is also less than ideal from an energy efficiency point of view.

A similar exercise can also be done for a chlor-alkali production unit operating on a solar park. In this case only 38% of the electricity produced in an hour could be consumed in that same hour.

If we combine a wind and a solar park (wind 117 MW and solar 126 MW), we would achieve, with an hourly correlation, a coverage of 65% renewable. This is slightly better when compared only to wind and much better than only solar. However, in this case, to also achieve 100% via battery storage and/ or hydrogen storage would still result in unrealistic figures.

<u>Consequences of a weekly correlation</u>

A weekly correlation would improve the situation. In our scenario the production is seen as renewable for the amount that matches with the renewable electricity production in the same week. The picture for this case is presented in figure 7.

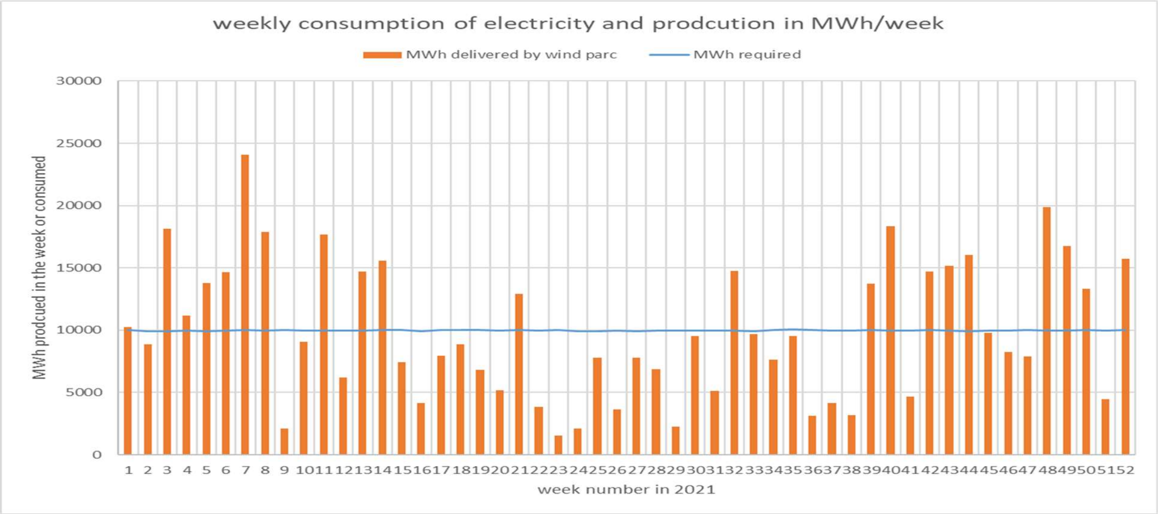

*Figure 7: The relationship between the production of the wind park and the demand of the electrolysis unit on a weekly basis*

Here, approximately 77% of the production can be counted as renewable. When 70% wind and 30% solar are combined, we achieve 85% renewable.

Consequences of a monthly correlation

As presented in Figure 4, this would result in 85.7% of the production being counted as renewable. If the production unit would operate on a solar park, the result would be 74.9%. The result becomes better still if we combine a wind and solar park because the wind park normally has slightly lower output in the summer period (i.e. the period in which solar parks have the highest output).

For a monthly correlation, the best combination would be 70% of wind and 30% solar (in other words a combination of a wind park of 117 MW and a solar park of 126 MW). If a monthly correlation could be applied on this basis a coverage of approximately 94% renewable could be achieved (as presented in figure 8).

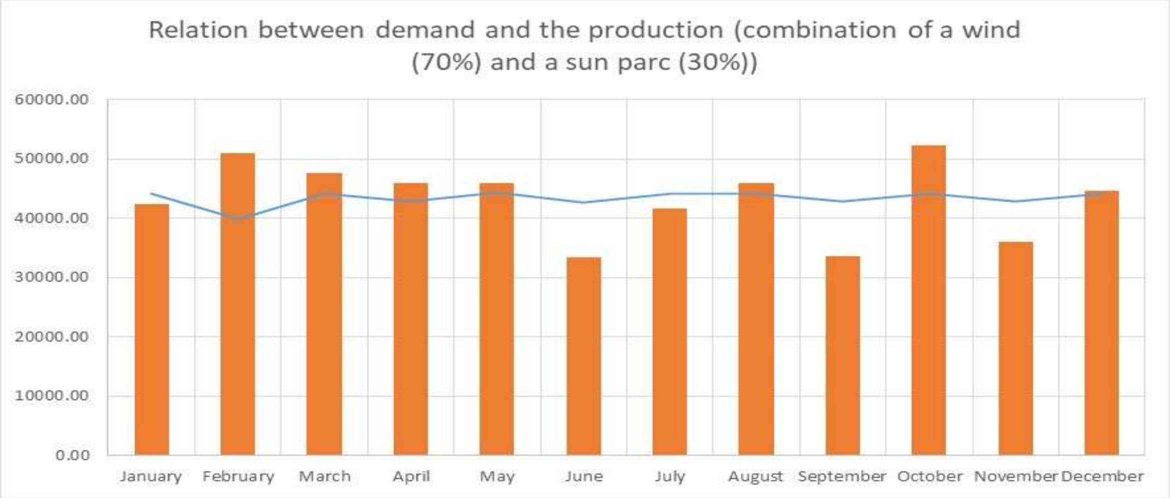

*Figure 8: The relationship between the production of the wind park (70%) and solar park (30%) and the demand of the electrolysis unit on a monthly basis*

Consequences of a quarterly correlation

The same calculations can be made for a quarterly correlation but for this case there is no real improvement in the overall situation (resulting in 85.7% renewable).

Consequences of a half-year correlation

If any correlation could be applied over a half year, this would result in 99.5% renewable for the example above.

## Summary

Renewable electricity production (wind and solar) is rather unstable and fluctuates highly when compared to the rather stable consumption requirements of a chlor-alkali production unit (or any other large electricity consumer).

This makes it very difficult to classify hydrogen production (as a by-product from chlor-alkali production) as renewable or RFNBO if upcoming rules stipulate that the electricity has to be produced and consumed in the same (short) time period. The time periods under consideration range between the same hour up to the same month.

If in the same hour, only approximately 58% of the production would be considered renewable (65% if solar and wind parks are combined). This could only be brought to 100% if unrealistic amounts of battery storage capacity or hydrogen storage (and reversion back to electricity) would be available. In such cases energy consumption would increase with 4.6% (for use of batteries) or 106% (for conversion to hydrogen). The other option could be to increase the capacity of the chlor-alkali plant by a factor of 2.6 and then have large amounts of chlorine, caustic and hydrogen storage. Besides also requiring huge investments, it would also result in a conflict around permitting and safety as one month of storage would be required.

In the case of a weekly correlation, only involving wind 77% renewable would result and for a combination of 70% wind and 30% solar, this would be 85% renewable. Better results can be obtained if a monthly correlation could be used (especially if we combine solar and wind parks). In such a case a coverage of 94% renewable could be obtained.