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TSO2020 Report – Activity 3

Cost-Benefit Analysis (CBA) Modelling - A description of the facility optimisation and contribution to local grid stability

Report no.: Activity 3, Task 2/3.
Date: 30 April 2019

Project name:	TSO 2020 electric 'transmission and storage options' along the TEN-E and TEN T corridor for 2020"
Report title:	Cost-Benefit Analysis (CBA) Modelling - A description of the facility optimisation and contribution to local grid stability
Owner of the Activity 3:	European Association for Storage of Energy (EASE)
Leader of the Task 2:	CIRCE
Date of issue:	30 April 2019
Document status:	Final version
Dissemination level:	Public

Acknowledgement:

Co- financed by the Connecting Europe Facility of the European Union

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EXECUTIVE SUMMARY

Objectives

This report is the second deliverable of Activity 3 of the TSO 2020 project. The objective of Activity 3 is to analyse the total value to the society and the project's business case in the market environment. This deliverable focusses on the grid-related contributions to both. It assesses the contribution to local grid stability of the electrolyser considered for the Eemshaven region in Northern Netherlands.

The approach that is considered for this Task studies the impact of the electrolyser on integration of locally generated renewable energy (mainly offshore wind) and integration of the COBRAcable HVDC interconnector with Denmark. It is important to evaluate and compare how different technology options (e.g. Power-to-Gas, battery storage) can play a role to stabilise the power grid and can be operated effectively. Contribution to local grid stability is defined in the context of this deliverable as: outcomes of the grid modelling that evaluate the effect on network congestions, on Renewable Energy Sources (RES) curtailment and on voltage stability in the Dutch network through the operation of an electrolyser or battery. These effects have been assessed through their corresponding key performance indicators (KPIs) in the societal cost benefit analysis performed in Task 1[1]. Task 1 Report[1] also includes the assessment of other KPIs related to Grid modelling: Reduction on grid losses, avoided transmission upgrade and energy not served. The objective of Task 2 is the assessment of the effect in the network of the electrolyser/battery. Since this analysis is intimately related to the CBA study and the obtained KPIs feeds the CBA itself, for the sake of avoiding redundancy those KPIs are not included in Task 2 report. Additionally, this report also includes a qualitative assessment of the beneficial impact of the electrolyser/battery in local voltage stability through reactive support.

Methodology

To assess the effect on the relief of the congestions in the Dutch network due to the installation of an electrolyser or battery in Eemshaven, both options with a rated power of 300 MW, the devised methodology is based on Optimal Power Flow analysis.

The Optimal Power Flow (OPF) optimises a certain objective function in a network whilst fulfilling equality constraints (the load flow equations) and inequality constraints (e.g. generator active and reactive power limits). One of the objective functions of the OPF is the minimisation of costs function, in which the goal is to supply the system under optimal operating costs. More specifically, the aim is to minimise the cost of power dispatch based on non-linear operating cost functions for each generator and on tariff systems for each external grid.

In order to perform an Optimal Power Flow (OPF) analysis, it is paramount to develop a network model of the area under analysis. Optimal Power Flow analysis is needed since the methodologies used for KPI assessment are based in this kind of assessment. This network model must comprehensively include and characterise all the elements comprising the power system and describe all their electrical parameters.

Finally, all the scenarios developed for the market analysis, namely the conservative, reference, progressive and progressive+ scenario (see report Task 1[1]), have been translated into Grid Scenarios, which implies the development of a total of four different network scenarios with three variants each one of them (base, base+electrolyser and base+battery). Each scenario modifies the number and type of the generators in order to match the overall values stated in the Market Scenarios (see report of Task 1). It implies that some of the currently installed generators are phased-out, others change their technology

[1] Cost-Benefit Analysis (CBA) Modelling – P2G project's value to society

(i.e. coal moving to biomass), new RES installations are included in the network model[2] [3] and some existing RES installations are repowered.

It is important to notice that the Market model used to assess KPIs for the societal cost benefit analysis performed in Task 1, are obtained at country level. Therefore, the scale of the Grid analysis must be the same and the network model must cover the whole Netherlands (see Figure 0-1).

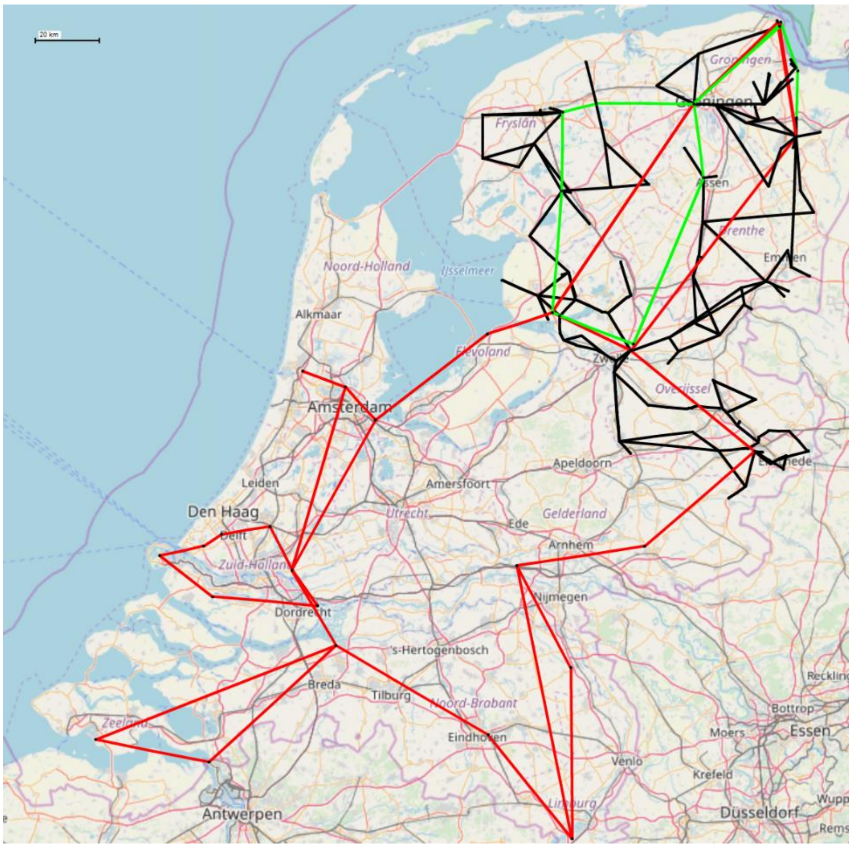

Figure 0-1. Final NL network display (Source: CIRCE)

Key results

The results obtained from the analysis prove that both the electrolyser and the battery have a positive impact on the congestion reduction in the Dutch network, with the electrolyser outperforming the battery in most scenarios. The following trend is observed: The impact of the electrolyser/battery in the reduction of the congestion decreases as the RES installed capacity increases, replacing generation with higher marginal cost. This is true for most scenarios (except for Progressive scenario in the case of the electrolyser and Progressive and Reference in the case of the battery). The electrolyser contributes to a higher reduction of the congestion level compared to the battery, except for the conservative scenario.

Electrolyser and battery are also beneficial to better exploit RES sources thus reducing the curtailment of them. Instead of curtailing surplus energy, it can be stored (battery) or transformed to other energy vectors using P2G technologies (electrolyser). Electrolyser outperforms battery in most scenarios analysed (except for Progressive+ scenario although similar values are obtained) due to fact that battery's energy absorption ability is limited by its state of charge, unlike the electrolyser.

[2] "Rijksdienst voor Ondernemend Nederland," [Online]. Available: https://www.rvo.nl/subsidies-regelingen/bureau-energieprojecten/lopende-projecten/windparken.

[3] "4C Offshore," [Online]. Available: https://www.4coffshore.com.

The contribution of an electrolyser/battery to voltage support has been assessed additionally. The impact is also positive since the electrolyser/battery is able to keep the voltage of nodes in its vicinity inside the allowed limits (0.95 p-u—1.05 p.u.) by means of the provision of reactive power. The battery/electrolyser can provide reactive power through the use of a Power Conversion System. Same reactive power capability is considered for both options and limited to a maximum of 210 MVAr. Battery and electrolyser are modelled identically, as a source able to provide the same rated active and reactive power.

Recommendations

The results presented in this study are valid for the considered scenarios, system boundaries and the constraints of the performed analyses, assuming that the 300 MW electrolyser is a 'first mover' in the Eemshaven region. Constraints of the analyses are explained throughout the document. The most relevant one is that the network model has been built based on an initial dataset lacking some needed information and has been completed with other open data sources. Therefore, the accuracy of the final network model cannot be guaranteed.

The positive impact of the electrolyser and the battery on the contribution to grid stability has been analysed through the assessment of the reduction in network congestion and local voltage support, keeping voltage limits between 0.95 p.u.[4] and 1.05 p.u[5] . This second deliverable of Activity 3 provides a deeper insight into the benefits to the system due to the installation of the electrolyser or battery. Nevertheless, due to lack of dynamic data of the network and its assets no transient and dynamic stability analysis have been performed. Activity 2, on the other hand, focusses on this subject providing valuable insight on the performance of the electrolyser to keep the grid stable.

It is important to mention that congestion in the network model is closely linked to the generation mix of a specific scenario. The nodes selected as the connection point for the different generators is a best estimate for each scenario. This has an impact in the assessment of the congestion according to the devised methodology (see section 3.1). In the same vein, the selection of the fuel for a specific generator has been estimated to match the indications and the generation mixes established by the different scenarios. This estimate may also have an impact on congestion assessment. More information on this specific issue, if available, could lead to more accurate results.

Additionally, performing a replicability and scalability analysis, trying to define the size limits and optimal placements of a potential number of electrolysers across the Dutch network, could provide additional valuable insights. The aforementioned analysis is inside the scope of Activity 5: "Analysis to scale-up to mass application (business plan)" and, hence, the outcomes and methodologies developed in the framework of Activity 3 could be relevant inputs for Activity 5.

From the grid stability standpoint alone, the fact that the electrolyser is not able to deliver back the energy to the grid is a limitation. It would be interesting for further studies to consider this capability by adding systems capable of producing electricity from hydrogen (i.e. fuel cells). Of course, the whole roundtrip system efficiency should be taken into account, as it could jeopardise the impact of such a system.

[4] p.u." stands for "per unit". In the power systems analysis field of electrical engineering, a per-unit system is the expression of system quantities as fractions of a defined base unit quantity.

[5] "Parameter related to voltage issues, ENTSO-E guidance document for national implementation for network codes on grid connection", 16 November 2016

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1 INTRODUCTION

The aim of the TSO 2020 project is to facilitate flexibility in the power system in the Eemshaven area to allow for the integration of variable renewable energy in the Northern Netherlands region (see Figure 1-1) , also further referred to in this report as Groningen-Drenthe-Friesland region (GDF), and the landing of the COBRA cable HVDC interconnector. The project specifically addresses the consequences of (possible) congestion in the local grid. There is a large volume of generation capacity (from coal and wind), together with the landing of submarine interconnection, situated in this area combined with relatively low demand.

Various technology options, such as Power-to-Gas (P2G), battery or conventional grid reinforcement, can be envisaged in order to address these challenges, provide the required flexibility and help the Renewable Energy Sources (RES) integration. The effect and contribution of the two first options in the local grid stability are assessed in this deliverable.

The different technology options (i.e. Power-to-Gas and battery) deployed in the project have indeed the potential to relieve congestion stress on the available grid in the region, and can be remunerated for these services by the TSO (Transmission System Operator), who will be able to postpone/refrain from further grid expansion. The relief of congestions has a strong impact, allowing lower marginal costs generators to deliver power, thus provoking a more efficient and cost-effective operation of the grid. The reactive power provision of the options analysed can also contribute to keep voltage stable in the occurrence of voltage disturbances.

Activity 3 has goal to analyse the **total value to the society** and the **project's business case** in the market environment.

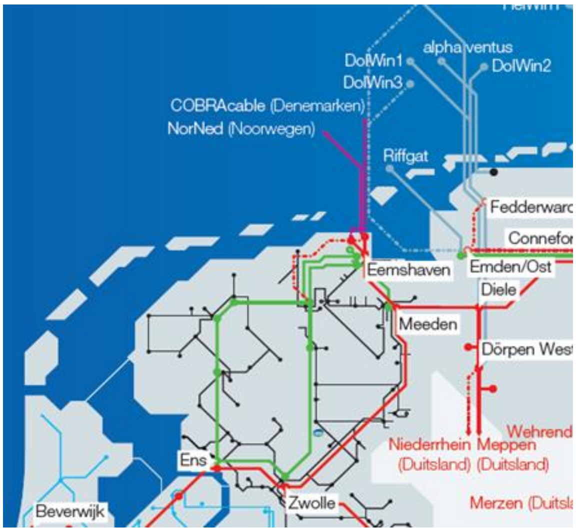

Figure 1-1. Grid lay-out northeast Netherlands. (source: TenneT TSO B.V.)

Activity 3: cost benefit analysis (CBA) modelling of an electrolyser in the Eemshaven region involves the following tasks:

- Task 1: Assessing the value of the electrolyser to society;
- Task 2: Assessing the contribution of the electrolyser to local grid stability;
- Task 3: Assessing the business model and operational scheme of the electrolyser.

This document is the deliverable of Task 2.

This report is organised as follows chapter 2 explains the methodology used to build the network model (topology, onshore and offshore wind generators, loads...). Next, chapter 3 details the methodologies for the calculation of the local stability assessment (Congestion Assessment and Local voltage stability). Once the methodologies are defined, the local stability assessment will be calculated in the network model that will be presented in chapter 4. Finally, in chapter 5 the conclusions obtained in this work are showcased.

2 GRID MODELLING

2.1 Network model

To assess the effect on the relief of the congestions in the Dutch network due to the installation of an electrolyser/battery, the devised methodology is based on Optimal Power Flow analysis.

The Optimal Power Flow (OPF) optimises a certain objective function in a network whilst fulfilling equality constraints (the load flow equations) and inequality constraints (e.g. generator active and reactive power limits). One of the objective functions of the OPF is the minimisation of costs function, in which the goal is to supply the system under optimal operating costs. More specifically, the aim is to minimise the cost of power dispatch based on non-linear operating cost functions for each generator and on tariff systems for each external grid.

In order to perform an Optimal Power Flow (OPF) analysis, it is paramount to develop a network model of the area under analysis. This network model must comprehensively include and characterise all the elements comprising the power system and describe all their electrical parameters. A non-exhaustive list of the elements to be included along with their electrical parameters is the following:

1. Electrical lines and grid topology:
    a. Length
    b. Capacity
    c. Reactance
    d. Resistance
    e. Capacitance
    f. Identification of the connection nodes of the line
2. Loads:
    a. Active and reactive power
    b. Hourly profile for the whole year
    c. Identification of the connection node
3. Generators:
    a. Active and reactive rated power
    b. Cost curve describing the operating cost for the generator
4. Hourly power profile during the whole year for renewable energy sources (RES)
5. Interconnection with neighbouring countries
    a. Capacity of the interconnection between countries
    b. Tariff system or exchange profile
    c. Net transfer capacity between countries/areas

The network model that has been developed is based on different sources.

The first one to be used was the dataset provided by TU Delft for the execution of Activity 2 of the TSO 2020 project[6]. This dataset covered some part of the GDOF (Groningen/Drenthe/Overijssel/Friesland) area in the Netherlands.

Grid nodes provided in the TU Delft dataset have been geo-localised, this way the location of nodes has been identified which is important to later define generation, loads and renewable profiles. Figure 2-1 shows the model of TU Delft and geo-localisation process performed by CIRCE.

[6] Integration of Power-to-Gas Conversion into Dutch Electrical Ancillary Services Markets, Víctor García Suárez, José L. Rueda Torres, Bart W. Tuinema, Arcadio Perilla Guerra and M.A.M.M van der Meijden, Enerday 2018, 12th Conference on Energy Economics and Technology, April 2018

Length of several lines have been corrected according to the obtained coordinates of the nodes (lines initially with 1 km length). Although it does not impact the power flow analysis (providing that absolute values for resistance, reactance and capacitance are correct), it is important to have correct length values when assessing the deferred network upgrades for each scenario and case.

In order to complete the network model, the GDOF area had to be completed (properly representing the 110 kV, 220 kV and 380 kV networks) and a simplified representation for the rest of NL had also to be included. Consequently, it was needed to use complimentary data sources which include the missing information.

Additionally, the network model has been completed to properly represent the expected progress of the Netherlands (NL) transmission power system for 2030 considering the following information:

1. Ten Year Network Development Plan 2018 (TYNDP2018)[7] and Project of Common Interest (PCI) projects[8] affecting NL network: upgrading of the lines and corridors and interconnection with other countries
2. Expected planning for the wind energy deployment, identifying the future onshore and offshore wind projects and potential sites.

[7] European Network of Transmission System Operators (ENTSO-E), «TYNDP 2018 - Scenario Report,» 2018.

[8] "Projects of Common Interest," [Online]. Available: https://ec.europa.eu/energy/en/topics/infrastructure/projects-common-interest.

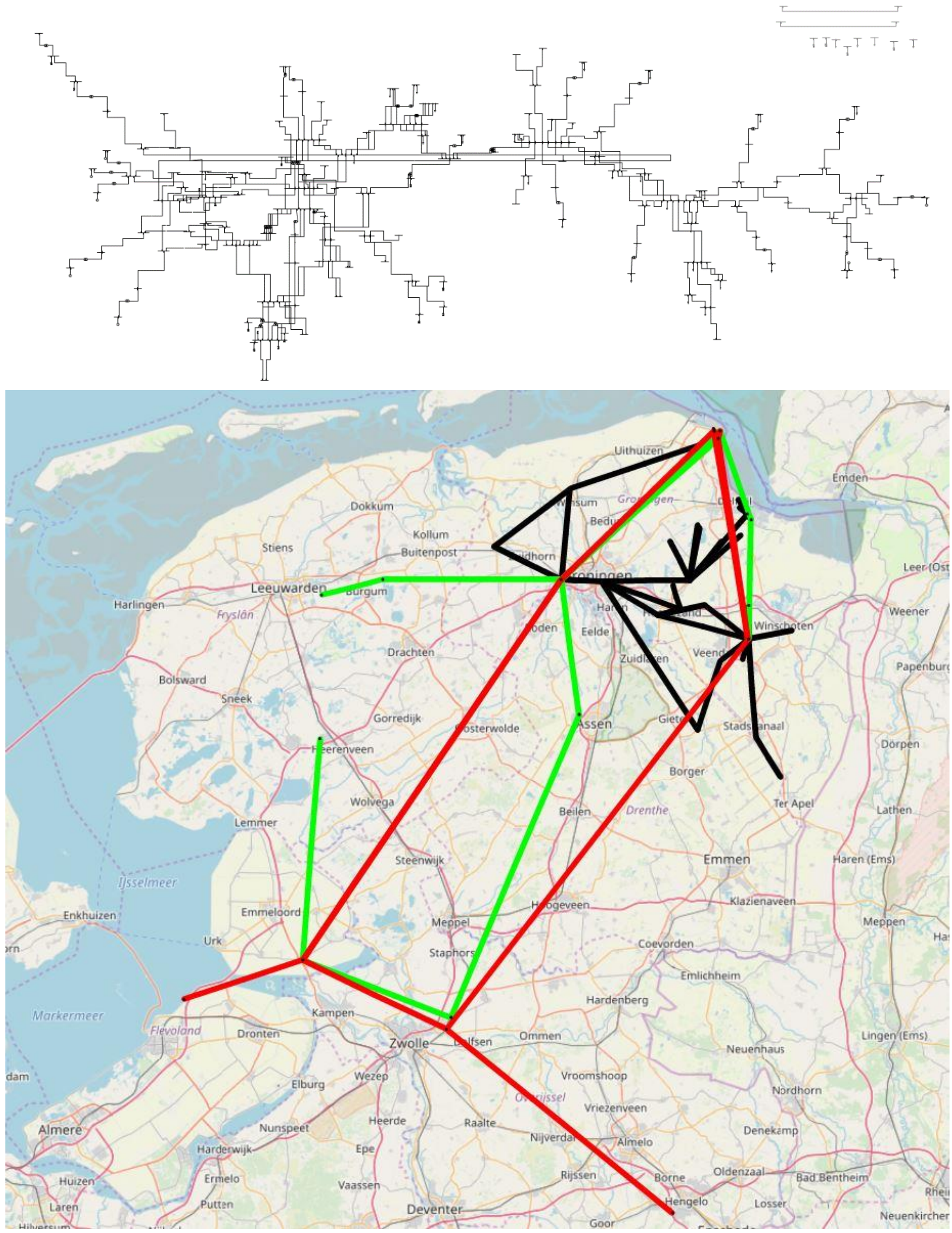

Figure 2-1. Comparison between the grid provided by TU Delft "as is" (top) and after the geo-localisation process performed by CIRCE (bottom) (Source: TU Delft and CIRCE)

In order to include a simplified representation for the NL network apart from the GDOF area, the information provided by TenneT TSO B.V. on its website has been used[9].

It will also serve for completing the missing lines at 220 kV level in the TU Delft dataset.

[9] Tennet, "Overzicht componenten 380kv en 220kv net," 2017. [Online]. Available: www.tennet.eu.

The information available from TenneT TSO B.V. provides detailed information of the Dutch 220 kV, 380 kV and 450 kV (DC) networks.

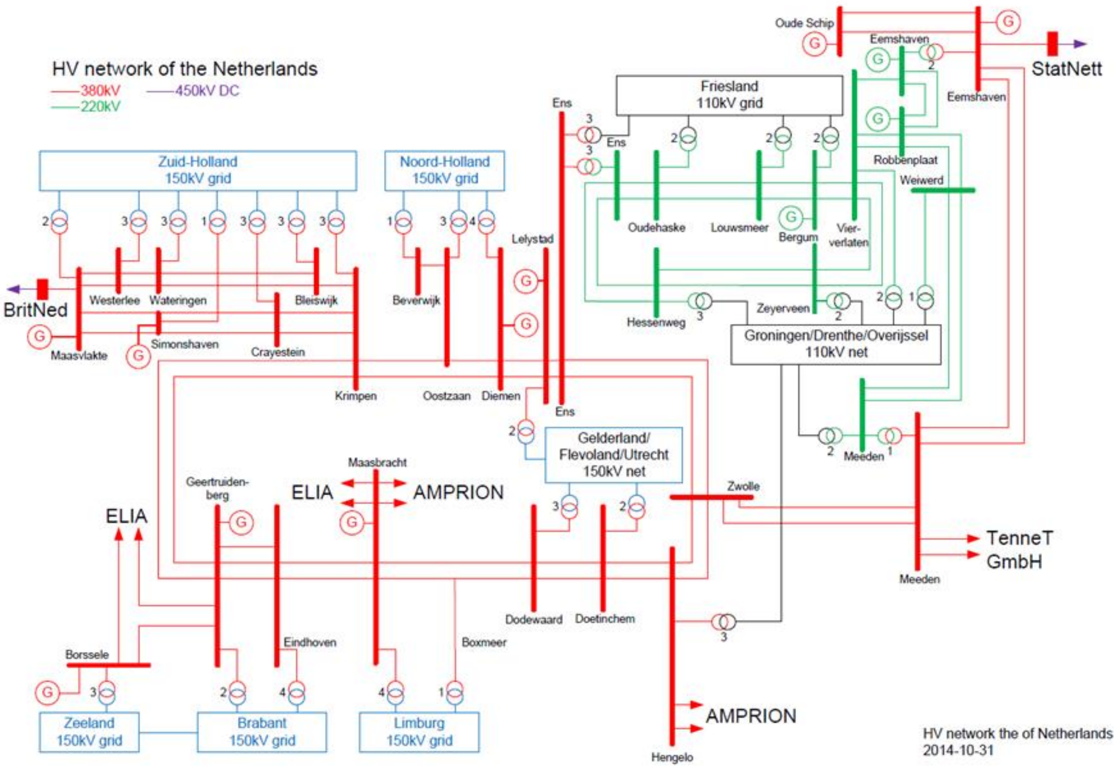

Figure 2-2. Network information provided by TenneT (source: Tennet TSO B.V.)

The missing 110 kV network belonging to the GDOF area has been built using the information provided by HoogspanningsNet[10]. With this database, all the missing 110 kV lines have been identified, as well as the corresponding network nodes along with their geographic coordinates. This database has proven to be very useful, but it lacks a lot of electrical information regarding the lines themselves, being the rated capacity (MVA) the only electrical parameter provided. Electrical parameters from the dataset provided by TU Delft have been used as reference to complete the missing information. For each line with missing parameters, the closest one in terms of rated capacity has been chosen from those present in the TU Delft dataset. Then, the resistance, reactance and capacitance values per unit length of the incomplete line are matched to those of that selected line.

As it has been aforementioned, to reflect the expected progress of the NL transmission system by 2030 with the highest fidelity possible, the network model has been complemented using TYNDP18 recommendations[11].

TYNDP 2018 is the most comprehensive and up-to-date planning reference for the Pan-European electric transmission network. It presents and assesses all relevant Pan-European projects at a specific time horizon as defined by a set of scenarios.

Table 2-1 shows cases of the projects that have been taken into account to finally model the Dutch network. Some of the TYNDP18 projects affecting the area have not been included since there is no

10 "HoogspanningsNet," [Online]. Available: https://www.hoogspanningsnet.com/.

11 https://tyndp.entsoe.eu/tyndp2018/projects/projects

information to properly model them. NorNed, COBRAcable and project 348 from TNYDP18 were initially included in the TU Delft dataset.

Table 2-1. TYNDP18 projects included in the network model (source: TYNDP18 [12])

TYNDP18 code.subcode	Expected Commissioning Year	Voltage level	Description
103.1490	2022	380 kV AC	Upgrade of existing 380 kV circuits between Ens and Zwolle from 2*2,5 kA to 2*4 kA circuits by replacing the conductors with High Temperature Low Sag (HTLS) conductors
103.1560	2018	380 kV AC	New 380 kV-line from substation Beverwijk to Bleiswijk with capacity of 2x1975 MVA; new 380 kV substation Vijfhuizen
103.1488	2020	380 kV AC	Upgrade of existing 380 kV circuits between Diemen, Lelystad and Ens from 2*2,5 kA to 2*4 kA circuits by replacing the conductors with HTLS conductors
103.1540	2023	380 kV AC	Upgrade of existing 380 kV circuits between Eindhoven and Maasbracht from 2*2,5 kA to 2*4 kA circuits by replacing the conductors with HTLS conductors
103.1539	2020	380 kV AC	Upgrade of existing 380 kV circuits between Krimpen and Geertruidenberg from 2*2,5 kA to 2*4 kA circuits by replacing the conductors with HTLS conductors
113.145	2018	380 kV AC	New 380 kV line double circuit DE-NL interconnection line.
260.1255	2030	450 kV DC	Interconnector between GB and NL with possibly NL and/or GB windfarms connected.
262.1257	2022	380 kV AC	Upgrade of the capacity of the cross border lines by replacing the current conductors with high performance (HTLS) conductors combined with the installation of

[12] https://tyndp.entsoe.eu/tyndp2018/projects/projects

TYNDP18 code.subcode	Expected Commissioning Year	Voltage level	Description
			additional phase shifting transformers in Zandvliet.
335.1506	2035	450 kV DC	One of two HVDC connectors including substations interfacing the Power Link Island and the Dutch power system.
335.1507	2035	450 kV DC	One of two HVDC connectors including substations interfacing the Power Link Island and the Dutch power system.
344.1541	2035	380 kV AC	Upgrade of existing 380 kV circuits between Zwolle, Hengelo, Doetinchem and Dodewaard from 2*2,5 kA to 2*4 kA circuits by replacing the conductors with HTLS conductors
346.1544	2025	380 kV AC	New 380 kV substation Tilburg; New 380 kV double circuit line 2645 MVA between Rilland and Tilburg
346.1543	2021	380 kV AC	New 380 kV substation Rilland; New 380 kV double circuit line 2645 MVA between Borssele and Rilland; Upgrade of existing 380 kV line Borssele-Geertruidenberg to 1975 MVA

Figure 2-3 shows the final network display using all the datasets.

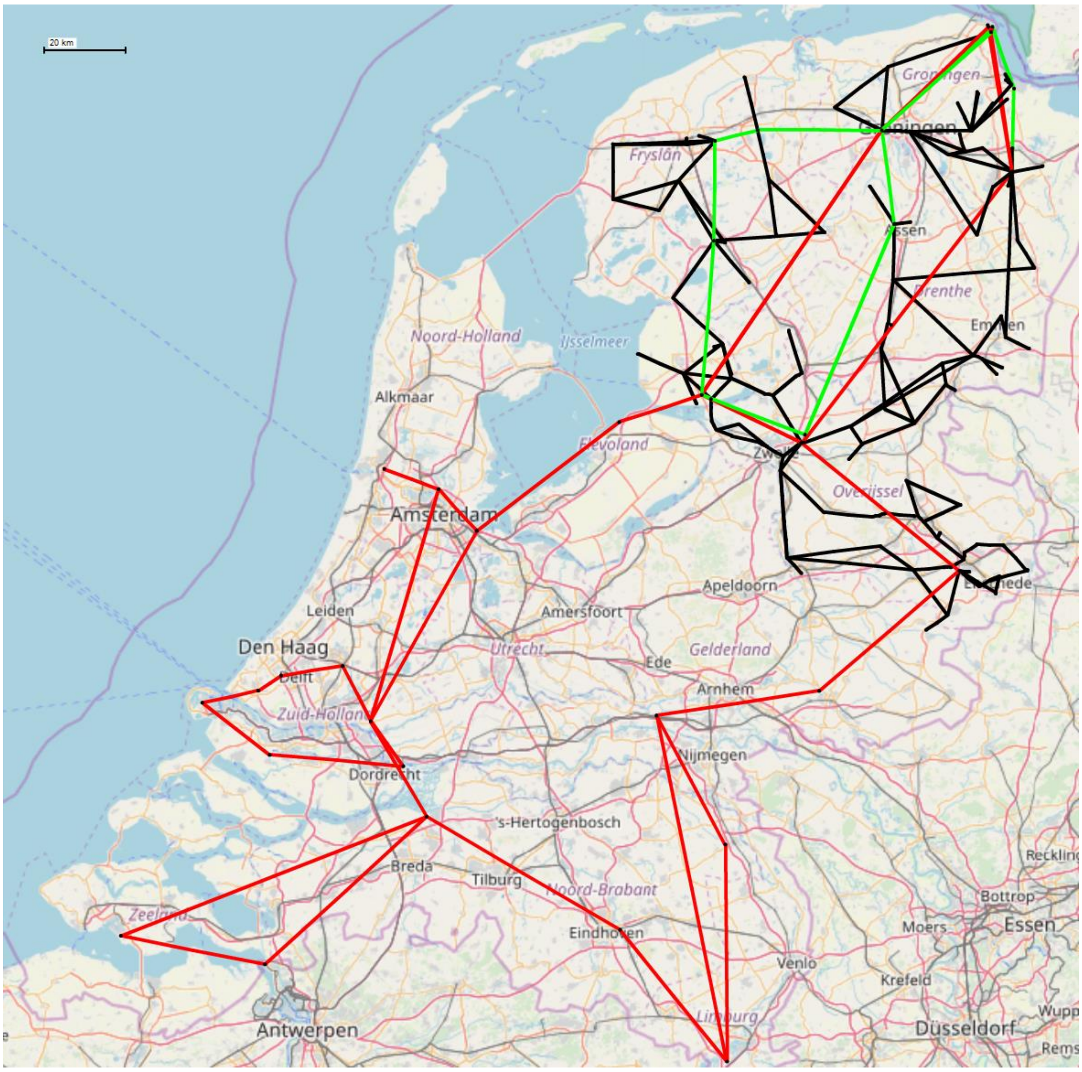

Figure 2-3. Final NL network display

2.2 Load estimation and allocation

The TU Delft dataset includes the loads connected in the considered portion of the GDOF area. Nevertheless, it is required to estimate the rest of the NL loads. Since there is no information apart from data at country level, it is needed to develop a method to estimate and allocate the loads across the NL network.

For the estimation of traditional demand, the devised methodology is as follows:

From "City Population"[13], a complete list of all the settlements with their corresponding population for each of the different provinces of NL have been obtained. For every single settlement, its geographical coordinates have been found.

From the ENTSO-E database[14], the maximum demand in NL for a reference year has been obtained. That value has been distributed among the different settlements proportionally to their population. With this

[13] "City Population," [Online]. Available: https://www.citypopulation.de/Netherlands.html.

[14] "ENTSO-E Data Portal," [Online]. Available: https://www.entsoe.eu/data/data-portal/.

method, a geographic distribution of the load for the whole area of the Netherlands is obtained. The last step is to allocate those settlement loads to the closest network node[15].

It is important to mention that the main outcomes obtained using the methodology are the distribution factors of the total load across the network nodes. Load values will be scaled up or down to match the values provided by the different Scenarios developed in the Market Model.

The following formula summarises this process:

$$dfL_n = \frac{L_{n,ref}}{L_{ref}}$$

Where dfL_n is the distribution load factor for a network node n, $L_{n,ref}$ (MW) is the total load in the network node n obtained after the allocation process of the settlement loads, as previously explained, and L_{ref} (MW) is the maximum demand for NL in the reference year.

Then, for a specific scenario, the load in a certain network node n ($L_{n,SCENARIO}$) is the following:

$$L_{n,SCENARIO} = dfL_n \times L_{SCENARIO}$$

Where $L_{SCENARIO}$ (MW) is the maximum traditional demand for NL according to that scenario.

The hourly profile for the whole reference year has also been obtained from the ENTSO-E database[14]. This profile has been normalised and applied to every network load to produce an hourly profile for the whole year, to be used in the simulations of the Network scenarios. Therefore, the hourly load value for a node n ($L_{n,h}$) for the traditional demand is as follows:

$$L_{n,h} = L_{n,SCENARIO} \times \frac{L_{ref,h}}{L_{ref}}$$

Where $L_{ref,h}$ is the NL hourly demand (MW) for that specific hour h in the reference year. Since there is no information about more detailed hourly profiles for different zones in the Netherlands, the same profile is assumed for every node in the network.

The rest of the components of the demand considered in the Market Model (electrical vehicles, electrical heat pumps and additional industrial baseload demand for some scenarios) have been distributed according to the load distribution factors calculated above. The hourly profiles have been obtained directly from the Market Model simulations (see report Task 1) and normalised and scaled for the different network nodes following a similar approach to the traditional demand one and added to it to get the final demand profile.

[15] The product of this methodology is an estimation of how the loads are distributed in the network, of course it is an approximate method and there is no way to check its accuracy since there is no available data at the required level of detail.

2.3 Generation estimation and allocation

2.3.1 Current state generation

The selected generators for each scenario have to match the values proposed by the Market Model scenarios (see report Task 1).

As a first step, a reference current state scenario has been developed in order to find and characterise the current generation in NL. This will serve as a cornerstone and enable us to scale up the generation to the required values dictated by the different scenarios.

The conventional and dispatchable generators have been obtained from the RE Europe dataset[16]. This dataset provides the installed power, the fuel type and the geographic coordinates for every generator. Using the geographic information, the generators have been located and connected in the model to the closest network node. From the results of the Market Model analysed in Task 1, generation cost curves have been obtained for the different technologies existing in the network model.

Regarding wind generation, the list of all the current installed wind farms (see Table 2-2) is obtained from The Windpower website[17], along with their rated power and geographic coordinates. Figure 2-4 shows the wind farms in NL. Following the same approach as in the case of conventional generation, the windfarms have been connected to the nearest network node in the model.

Table 2-2. Main current onshore windfarms in NL[16]

Name	Power (MW)	Latitude	Longitude
Westereems	213.3	53.46	6.87
Princess Alexia Windpark	122.4	2.29	5.39
Zuidwester	90	52.69	5.59
Kreekraksluis	77.5	51.43	4.23
Delfzijl-Zuid	77	53.28	6.97
GroWind	63	53.44	6.85
Delfzijl Noord	62.7	53.33	6.92
Emmapolder	60	53.45	6.79

16 "The RE-Europe dataset," [Online]. Available: https://zenodo.org/record/35177#.WyJnw1UzaUk.

17 «The Windpower,» [En línea]. Available: https://www.thewindpower.net/.

Figure 2-4. NL wind farms location (Source: CIRCE)

Table 2-3. Main current offshore windfarms in NL[16]

Name	Power (MW)	Latitude
Borssele V	20	51.71
Gemini	600	54.18
Eneco Luchterduinen	129	52.41
Prinses Amalia	120	52.98
Egmond aan Zee	108	52.61

The installed photovoltaic power per municipality in the Netherlands has been obtained through the web portal Klimaatmonitor[18] and has been distributed among the nodes of the network, selecting the closest to the geographical location of the municipality.

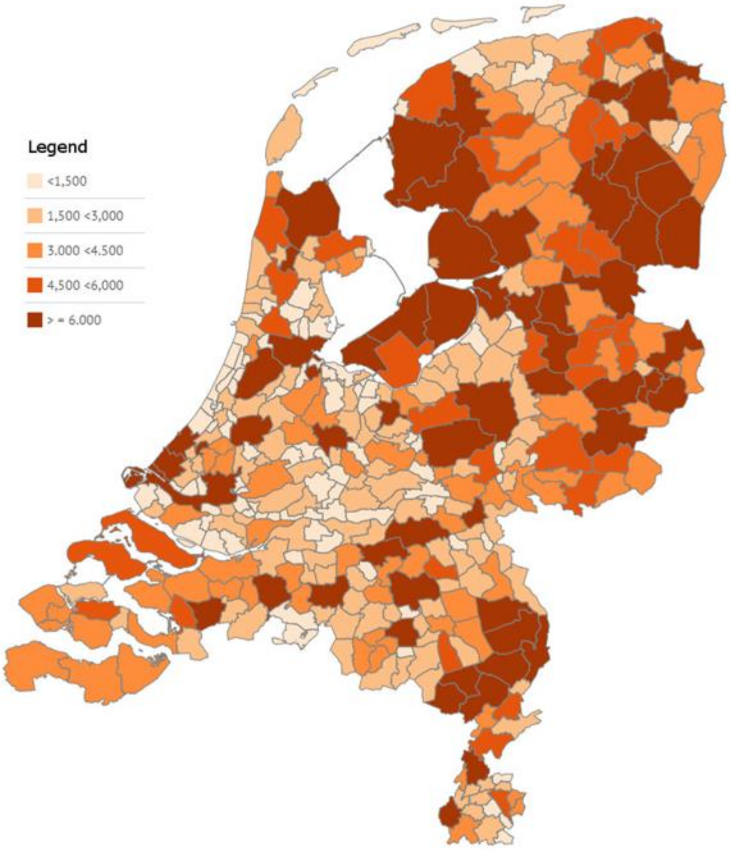

Figure 2-5. PV installed power per municipality in Netherlands[18]

Hourly power profiles for the whole year and the different RES locations (wind and PV) have been obtained from online database Renewables.ninja[19]. The database works by taking weather data from global reanalysis models and satellite observations. Two data sources are used:

- NASA MERRA reanalysis[20]
- CM-SAF's SARAH dataset (Copyright 2015 EUMETSAT)[21,22]

Solar irradiance data is converted into power output using the GSEE model (Global Solar Energy Estimator) written by Stefan Pfenninger[23]. Wind speeds are converted into power output using the VWF model (Virtual Wind Farm) written by Iain Staffell[24].

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18 "Klimaatmonitor database," [Online]. Available: https://klimaatmonitor.databank.nl/dashboard/.

19 "NINJA RENEWABLES," [Online]. Available: https://www.renewables.ninja/.

20 M. M. Rienecker, M. J. Suarez, R. Gelaro, R. Todling and others, "MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications," Journal of Climate, vol. 24, no. 12, pp. 3624-3648, 2011.

21 R. Müller, U. Pfeifroth, C. Träger-Chatterjee, J. Trentmann and R. Cremer, "Digging the METEOSAT Treasure—3 Decades of Solar Surface Radiation," Remote Sensing, vol. 7, p. 8067–8101, 2015.

22 SARAH dataset.

23 S. Pfenninger and I. Staffell, "Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data," Energy, vol. 114, pp. 1251-1265, 2016.

24 I. Staffell and S. Pfenninger, "Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output," Energy, vol. 114, pp. 1224-1239, 2016.

Apart from wind and photovoltaics, other renewable sources have been considered for the building of the network model and the scenarios as dictated by the Market Scenarios values. The current biofuel generators for this current state scenario are already included in the RE Europe dataset. Regarding other renewable sources like hydropower, the following list of existing run-of-river hydropower plants, which will remain unchanged for all the scenarios, is included and connected to their corresponding nearest network node in the model:

- Waterkrachtcentrale Alphen, with a rated power of 14 MW
- Waterkrachtcentrale Linne, with a rated power of 11 MW
- Waterkrachtcentrale Amerongen, with a rated power of 10 MW
- Waterkrachtcentrale Hagesteing, with a rated power of 1.8 MW
- Oosterscheldekering, with a rated power of 1.2 MW

2.3.2 Scaling and adjusting methodology

Each scenario developed in the Market Model (Conservative, Reference, Progressive and Progressive+) presents a different generation mix. In order to translate those scenarios to the Grid Model, it is needed to observe and respect the share and installed capacity of every generation technology while ensuring the stability of the grid model.

Some of the scenarios involve the phase-out of coal-based generation plants (and nuclear in certain scenarios). In order to match the generation mix when building the scenarios in the network model, the technology and fuel of some of those dispatchable generation units are changed.

Regarding offshore wind, a list with the planned offshore windfarms in the Netherlands has been obtained[25].

Table 2-4. Future planned NL offshore windfarms[25]

Name/designation	Power (MW)	Latitude	Longitude
Ten noorden van de Waddeneilanden (Tender 2022)	700	54.04	5.58
IJmuiden Ver Pre-2030	900	52.88	3.56
IJmuiden Ver 2026	1000	52.88	3.56
IJmuiden Ver 2025	1000	52.88	3.56
IJmuiden Ver 2024	1000	52.88	3.56
IJmuiden Ver 2023	1000	52.88	3.56
Hollandse Kust West (Tender 2020-2021)	1400	52.63	3.72
Hollandse Kust Zuid Holland III and IV (Tender 2019)	700	52.28	4.08
Hollandse Kust Noord Holland I and II (Tender 2019)	700	52.68	4.27

[25] "4C Offshore," [Online]. Available: https://www.4coffshore.com.

Name/designation	Power (MW)	Latitude	Longitude
Haliade-X	14	51.96	4.01
Hollandse Kust Zuid Holland I and II (Chinook)	760	52.33	4.01
Borssele V	20	51.71	3.00
Borssele 3 and 4	731.5	51.70	2.93
Borssele 1 and 2	752	51.68	3.07
Windpark Fryslan	382.7	52.95	5.23

The different scenarios will include some or the totality of these offshore wind parks until reaching the value of offshore wind energy installed stated by the scenario.

From "Rijksdienst voor Ondernemend Nederland" [26], the list of the future planned onshore wind parks is obtained. Some of these projects imply the removal or repowering of existing wind installations. Therefore, with the inclusion of the new windfarms, the list of existing ones has been updated, removing those that will be obsolete with the addition of the new projects.

Table 2-5. Future planned NL onshore windfarms

Name	Power (MW)	Latitude	Longitude	Existing parks to be repowered
Windplan Blauw	215	52.59	5.57	Klokbekertocht, Noordertocht, Rivierduintocht, Vuursteentocht, Dronten Solitair, Dronten, Irene Vorrink I, Irene Vorrink II, Irene Vorrink,
Windplan Groen	400	52.42	5.68	Lelystad-Meeuwentocht, Kubbeweg, Zeebiestocht, Windstroom, Olstertocht
Windpark DMOM	150	52.99	6.92	-
Windpark Eemshaven West	130	53.46	6.75	-
Windpark N33	120	53.16	6.91	-

[26] "Rijksdienst voor Ondernemend Nederland," [Online]. Available: https://www.rvo.nl/subsidies-regelingen/bureau-energieprojecten/lopende-projecten/windparken.

Name	Power (MW)	Latitude	Longitude	Existing parks to be repowered
Windpark Wieringermeer	400	52.86	5.00	Wieringen-1, Wieringen-2, Den Oever, Oom Kees, Waterkaaptocht, Scherventocht, EWTW, Wieringerwerf, Oudelandertocht, Middenmeer, Groettocht, Waardtocht, Groetpolder, Ulketocht
Windpark Zeewolde	300	52.36	5.36	Tureluurweg, Gruttoweg, Kluutmolen, Kluutweg, Wulpweg, Ibisweg, Dodaarsweg, Reigerweg, Lepelaarweg, Lepelaarpad, Schollevaarweg, Appelvinkweg, Sterappellaan, Bloesemlaan, Ooievaarsweg, Duikerweg, Bosruiterweg

Nevertheless, in some scenarios it is needed to deploy more onshore installed wind power to reach the onshore wind capacity values dictated by them. In order to consider this, some of the existing wind farms already included in the network model are scaled up until the value is matched.

A similar process has been followed for photovoltaic generation. The power of the current installations is scaled up to reach the installed power present in the different scenarios.

With respect to biofuel generation, some of the scenarios are based on the assumption that all biofuel installed capacity comes from certain generation plants affected by the coal phase-out that have decided to change the fuel powering them (see report Task 1). For other scenarios, the approach has been different. The total biofuel generation has been distributed among the eligible network nodes according to a factor derived from the information provided by Klimaatmonitor[27]:

- This database provides the total generation coming from biofuels per municipality in NL. This value is assumed to be relevant for future scenarios.
- The biofuel installed capacity per municipality for a specific scenario was obtained by distributing the total installed biofuel capacity proportionally to that value.
- With the geographic location of the municipality, the installed biofuel capacity is allocated to the nearest network node, obtaining this way a distribution factor per network node for biofuel generation.

Some of the Market Model scenarios (see report Task 1) consider the installation of "Other RES plants". In order to match those values in those scenarios, other RES plants have also been considered. Specifically, tidal and wave energy are considered in the network model since there is no detailed information about the technology and specifics of those Other RES installations in the market development scenarios.

For wave energy in the North Sea, the areas as shown in Figure 2-6 are considered[28].

[27] "Klimaatmonitor database," [Online]. Available: https://klimaatmonitor.databank.nl/dashboard/.

[28] H. C. Sørensen and J. Fernández-Chozas, "The Potential for Wave Energy in the North Sea," in 3rd International Conference on Ocean Energy, Bilbao.

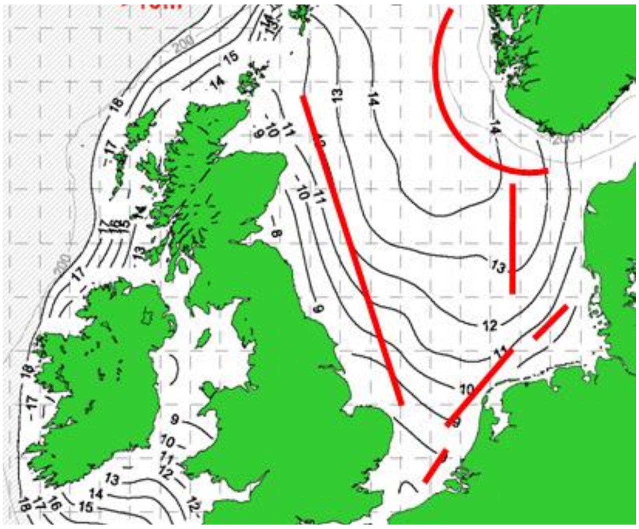

Figure 2-6. North Sea wave potential[29]

For each one of the three zones close to Netherlands, a wave installation has been considered with installed power of 100 MW.

For tidal energy, a selection of potential sites was obtained from "Energising Deltas" European project (see Table 2-6) along with their estimated installed power[30]. Figure 2-7 shows the location of the other RES plants in NL.

Table 2-6. Dutch tidal potential sites capacity [30] (source: Energising Deltas Project)

Site name	Capacity (MW)
Westerschelde	5
Waterdunen	2
Oosterscheldekering	58.8
Brouwersdam	40
TTC Grevelingendam	3
Stevinsluizen	4.5
Kornwerderzand	3
Marsidep	0.5
Wadden	10

[29] H. C. Sørensen and J. Fernández-Chozas, "The Potential for Wave Energy in the North Sea," in 3rd International Conference on Ocean Energy, Bilbao.

[30] P. Scheijgrond, "Energising Deltas," [Online]. Available: http://www.energisingdeltas.com/.

Figure 2-7. Other RES plants geo location (Wave and Tidal) (Source: CIRCE)

3 LOCAL STABILITY ASSESSMENT METHODOLOGY

The objective of this assessment pivots around three main effects on the grid stability provided by the addition of an electrolyser or a battery:

- Reduction of RES curtailment
- Reduction of congestions in the transmission system
- Improvement of the voltage stability of the local grid through the provision of reactive support

3.1 Reduction of RES curtailment

RES curtailment is an index which is obtained directly from the outputs of the OPF analysis. It is calculated as the difference between the maximum energy available at variable RES installation and the energy finally yielded by them.

Not all the RES available energy can be used, due to network technical problems such as overvoltage, over-frequency, local congestion, etc., RES production can be curtailed partially or totally. In the OPF simulation renewable generation will produce as much as possible unless curtailment is necessary due to grid bottlenecks or low consumption (no other curtailment situations are considered).

3.2 Congestion assessment

Regarding **congestion**, it has been assessed through the KPI devised in the deliverable "Cost-Benefit Analysis (CBA) Modelling – P2G project's value to society" belonging to Task 1 of the Activity 3. This value is directly derived from the results of the OPF.

Under the availability of sufficient transmission capacity, the merit order of the generators when dispatched to supply the demand can be respected. In this case, there is only one marginal generator, which is the last one in the merit order to be dispatched to satisfy the demand, i.e. the most expensive one, which sets the price and is only dispatched as much as needed (usually below its capacity limit) to cover the remaining demand.

A single congestion (see Figure 3-1), however, might prevent a cheaper generator with sufficient capacity to supply the remaining demand to be dispatched to the required level. This issue is caused by the grid not being able to absorb higher power injection levels at the generator's connection point. Given that the congestion prevents a cheap generator in the merit order curve (often a renewable energy generator with very low marginal cost) to produce as much power as required to satisfy the demand, another more expensive 'out-of-merit-order' generator is additionally required to be dispatched. This increases the total generation cost and thus, reduces social welfare as well as renewable energy penetration[31].

In order to assess congestion (see Figure 3-1) in the system the following proxy is used: for each hour, the merit order of the dispatched generators will be compared to the ideal situation, with no congestions at all. For all the congested generators, the difference between the real and the ideal dispatch will be calculated. The sum of all these values provides an indicator of the total congestion for a specific hour of the year. The congestion can be expressed then as the total year congestion, adding all the hourly values, or as an average hourly value.

[31] L. Halilbasic, F. Thams, R. Zanetti, G. Tsoumpa, P. Pinson y S. Chatzivasileiadis, «D13.1 Technical and economical scaling rules for the implementation of demo results,» BESTH PATHS Project, 2018.

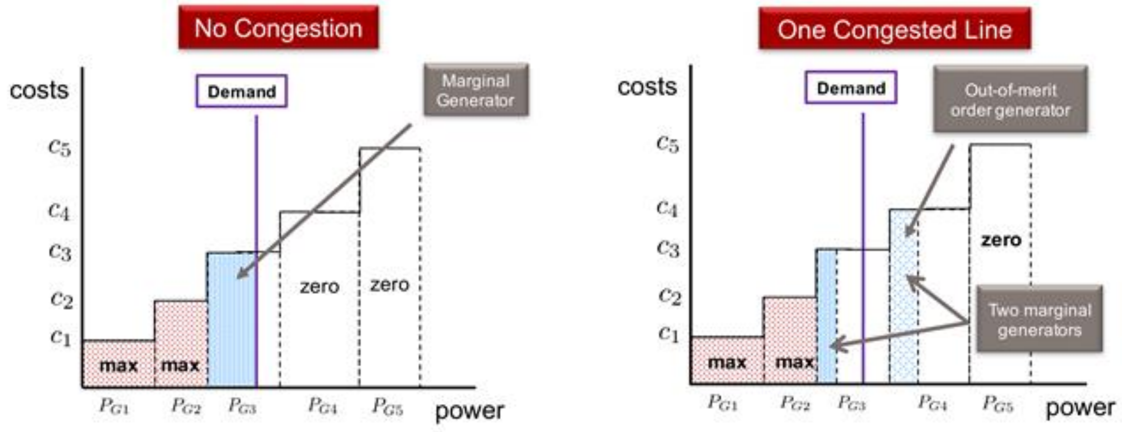

Figure 3-1. Comparison of merit order without and with congestion[31]. (source: Best Paths Project)

3.3 Local voltage stability

Regarding the **effect on local voltage stability** due to the electrolyser/battery, the following methodology is developed.

In the first place, in order to assess the separate effect of the electrolyser in helping to reduce voltage unbalances, the grid model is going to be reduced to focus on a smaller representation of the grid considering the network nodes in the vicinity of the electrolyser. Once the reduction has been carried out, a voltage unbalance will be created in one of the terminals, in order to check the effect the electrolyser may have.

In order to carry out this network reduction without losing the essence of the network model, equivalents of the network to be reduced have been implemented. The DIgSILENT PowerFactory tool[32] "Network reduction" will be used for this purpose.

The method used is the REI (Radial, Equivalent and Independent) equivalent [32]. The REI Equivalent is a methodology for network reduction which allows the flexibility to retain nonlinear elements within the reduced area or represent them with REI equivalent elements. It is possible to aggregate these reduced non-linear elements, with the option of grouping together generators of the same production (fuel) type. The advantages of the REI method are:

- Generators/loads of deleted nodes can be identified.
- Losses are kept at their initial value by using a Zero Power Balance Network.
- Electrical distances between boundary nodes and generation in the deleted network can be kept.
- The reduced networks can potentially be used with other static calculation modules besides load flow, such as contingency analysis and Optimum Power Flow.
- The ability to create equivalent injections per production type assists with system operator's obligations under European Network Codes.

The Figure 3-2 shows the reduced network. On the left side of the figure, the reduced network model is represented while on the right side, the complete network model is displayed.

[32] DIgSILENT PowerFactory Version 2019: User manual, Online Edition, DIgSILENT GmbH, December 2018"

Reduced Network	Complete Network
	

Figure 3-2. Reduced network vs Complete Network. (source= PowerFactory DIgSILENT)

From the image, it can be seen that the 110 kV network has been reduced along with the southeast portion of the 380 kV network.

It has been decided to produce a voltage unbalance in the terminal EOS/TEMP1 (Terminal bus number= 401) for several reasons:

1. Terminal 401 (latitude 53.4361 and longitude 6.8638) is very close to terminal 501 (latitude 53.4361, 6.8638) where the electrolyser is connected.
2. Terminal 401 has a lot of generation which could potentially produce unbalance as it has 4 generators connected (EOS/TEMP1 AWF, Emmapolder, GroWind, Windpark Eemshaven West). In the practice voltage problems are faced in the weaker parts of the network where no generation is connected. Conventional generators are set to keep a stable voltage at their connection point. Nevertheless, this node has been chosen as the unbalanced one since this is easier to create a reactive event.

In order to provoke the voltage discursion, generators connected to this node decrease the reactive power. The same effect could also happen if connected loads increase the reactive consumption.

This situation will be studied with the electrolyser and without electrolyser in order to evaluate the effect of the electrolyser. For this purpose, the terminals out of voltage range (i.e. 1.05 p.u.[33]- 0.95 p.u.)[34] will be assessed comparing both cases: Electrolyser ON/OFF. The same result is expected for the battery as the battery can also absorb and yield reactive power.

[33] "p.u." stands for "per unit". In the power systems analysis field of electrical engineering, a per-unit system is the expression of system quantities as fractions of a defined base unit quantity.

[34] "Parameter related to voltage issues, ENTSO-E guidance document for national implementation for network codes on grid connection", 16 November 2016

4 RESULTS

4.1 RES Curtailment reduction

The addition of an electrolyser or a battery can lead to a better exploitation of variable renewable energy sources. Instead of curtailing surplus energy, it can be stored (battery) or transformed to other energy vectors using P2G technologies (electrolyser).

For every scenario and technology (battery and electrolyser), the reduction of the RES Curtailment, expressed as the percentage of reduction of the Curtailment of the base case (no battery, no electrolyser) have been calculated. Results are shown in Figure 4-1 and in

Table 4-1.

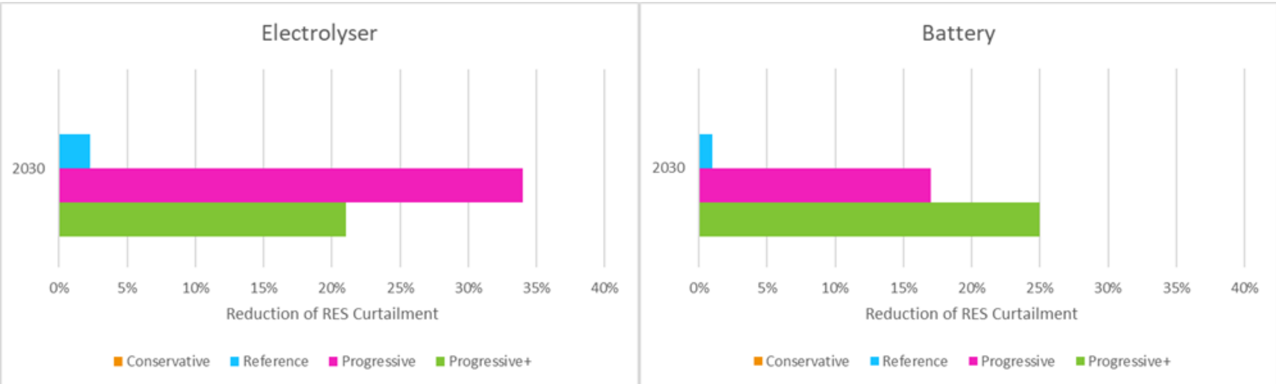

Figure 4-1. Reduction of RES Curtailment (percentage) with the use of Electrolyser (left) and Battery (right) (source: Circe based on Grid Model analysis)

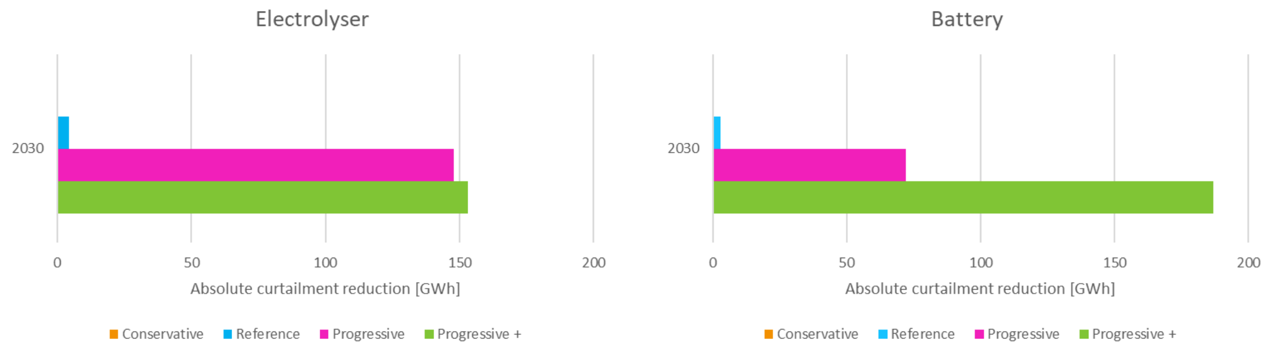

Figure 4-2. Reduction of RES Curtailment (absolute values) with the use of Electrolyser (left) and Battery (right) (source: Circe based on Grid Model analysis)

Table 4-1. Resulting values for 'RES Curtailment reduction'. (source: Circe)

	Electrolyser			
	2030			
	Cons.	Ref.	Prog.	Prog.+
RES Curtailment (%)	0%	-2%	-34%	-21%

	Battery			
	2030			
	Cons.	Ref.	Prog.	Prog.+
RES Curtailment (%)	0%	-1%	-17%	-25%

From the obtained results, the benefits of the electrolyser/battery in the reduction of RES curtailment are proved. Electrolyser outperforms the battery in most of the investigated scenarios. Battery's ability to absorb power is limited by its state of charge, there is no such limitation in the electrolyser. As it can be seen from the results the more progressive a scenario is the higher the reduction of the RES curtailment.

4.2 Congestion assessment

The avoidance of congestion in the grid is mainly due to better exploitation of generators with lower marginal costs. Adding an electrolyser or battery in the GDOF area allows to absorb power that otherwise should be curtailed, in the case of RES, or limited in the case of dispatchable generators.

This assessment has been reproduced for all scenarios developed for the market analysis (see report Task 1) in 2030. As explained in that report, due to the lack of available information regarding grid reinforcements up to 2040, a realistic network model for that term could not be built. Results for Grid-based KPIs, among which Congestion Assessment is included, could therefore be generated for 2030 scenarios only.

For every scenario and technology (battery and electrolyser), this KPI is expressed as the reduction of the congestion compared to the base case (without battery/electrolyser). The reduction in the congestion is measured as the average congested power per hour and expressed in MW.

The assessed technologies have a positive impact on the level of congestion for most of the scenarios developed in 2030, as can be seen in Table 4-2.

Table 4-2. Resulting values for 'Congestion reduction'. (source: Circe)

	Electrolyser			
	2030			
	Cons.	Ref.	Prog.	Prog.+
Congestion level (MW avg. per hour)	-204	-82	-3.2	-73

	Battery			
	2030			
	Cons.	Ref.	Prog.	Prog.+
Congestion level (MW avg. per hour)	-326	0	0	-57

The following trend is observed in Figure 4-3: for almost every scenario, the impact of the electrolyser/battery on the reduction of the congestion decreases as the RES installed capacity increases replacing generation with higher marginal cost. Nevertheless, congestion in the network model is closely linked to the generation mix of a specific scenario. The nodes selected as the connection point for the different generators is a best estimate for each scenario. This has an impact in the assessment of the congestion according to the devised methodology (see chapter 3). In the same vein, the selection of the fuel for a specific generator has been estimated to match the indications and the generation mixes established by the different market development scenarios. This estimate may also have an impact on congestion assessment. Nevertheless, as a general conclusion it can be stated that the addition of an electrolyser/battery has a sensible impact in reducing the congestion in the grid leading to a more efficient operation of the electric generators. Congestion is reduced in a quantity ranging from 3.2 to 204 MW_{avg}/hour in the case of the electrolyser and from 0 to 326 MW_{avg}/hour in the case of the battery as shown in Table 4-2.

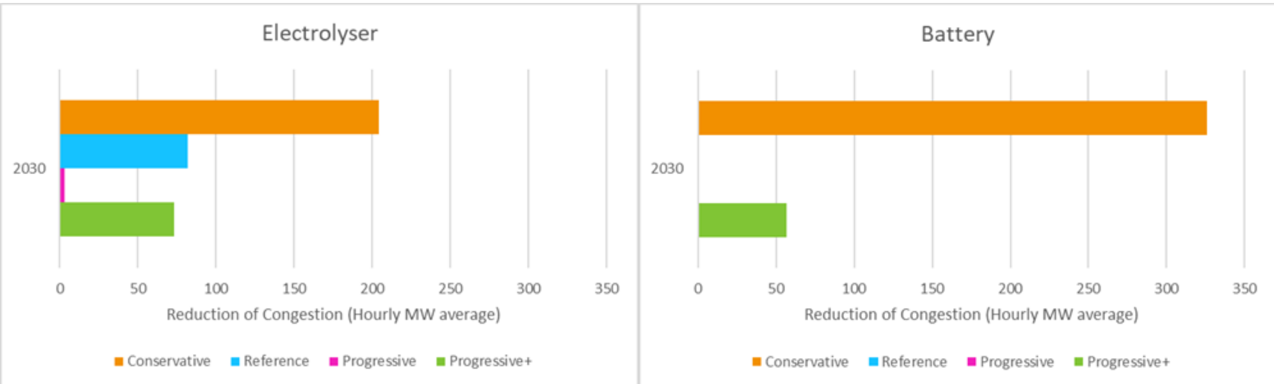

Figure 4-3. KPI 'Congestion'. (source: Circe based on Grid Model analysis)

4.3 Local voltage stability

Regarding the analysis of the local contribution to voltage stability, the analysis only has been performed for the 2030 Reference scenario as an illustrative example of the impact of the electrolyser/battery. The focus of this assessment is the separate effect of the device under analysis (battery or electrolyser) providing voltage support to the network.

Table 4-3 shows the terminals that are out of range (higher than 1.05 or less than 0.95) when the voltage unbalance occurs on terminal 401. The results obtained when the electrolyser is not connected are shown in the "Without Electrolyser" column and the results obtained when the electrolyser is connected are displayed in the "With Electrolyser" column.

Table 4-3. Voltage values after the unbalance with/without electrolyser (source: CIRCE)

Terminal	Latitude	Longitude	Voltage without electrolyser (p.u.)	Voltage with electrolyser (p.u.)
Diele	53.1258	7.3131	1.0722	1.0578
Gronau	52.2034	7.0346	1.0722	1.0578
15052	53.1234	6.9497	1.0613	1.0541

Terminal	Latitude	Longitude	Voltage without electrolyser (p.u.)	Voltage with electrolyser (p.u.)
15047	53.4247	6.8735	1.0560	1.0490
15048	53.4247	6.8735	1.0560	1.0490
15049	53.4247	6.8735	1.0560	1.0490
12027	53.1234	6.9497	1.0534	1.0468
12002	53.3030	6.9568	1.0532	1.0466
12042	53.3030	6.9568	1.0532	1.0465
12035	53.4363	6.8784	1.0525	1.0459
12024	53.4363	6.8784	1.0525	1.0459
12023	53.4363	6.8784	1.0525	1.0459
12022	53.4363	6.8784	1.0525	1.0459
12031	53.4363	6.8784	1.0524	1.0458
12007	53.4247	6.8735	1.0524	1.0458
12017	53.4247	6.8735	1.0524	1.0458
12016	53.4247	6.8735	1.0524	1.0458
19000	53.3030	6.9568	1.0520	1.0454
104	54.1833	5.8833	1.0519	1.0454
202	54.1833	5.8833	1.0519	1.0454
301	54.1833	5.8833	1.0519	1.0454
15053	53.2127	6.4784	1.0518	1.0440
17008	53.4361	6.8638	1.0518	1.0453
17009	53.4361	6.8638	1.0518	1.0453
17010	53.4361	6.8638	1.0518	1.0453
11115	53.4361	6.8638	1.0517	1.0452
17001	53.4361	6.8638	1.0517	1.0452
17002	53.4361	6.8638	1.0516	1.0452
11141	53.4361	6.8638	1.0516	1.0451
11142	53.4361	6.8638	1.0516	1.0451

Terminal	Latitude	Longitude	Voltage without electrolyser (p.u.)	Voltage with electrolyser (p.u.)
11203	53.4363	6.8784	1.0516	1.0451
11204	53.4363	6.8784	1.0516	1.0451
11005	53.4363	6.8784	1.0515	1.0451
11124	53.4363	6.8784	1.0515	1.0451
11127	53.4363	6.8784	1.0515	1.0451
11128	53.4363	6.8784	1.0515	1.0451
11154	53.4361	6.8638	1.0515	1.0450
11153	53.4361	6.8638	1.0515	1.0450
11237	54.1833	5.8833	1.0515	1.0450
17	54.1833	5.8833	1.0515	1.0450
11152	53.4361	6.8638	1.0515	1.0450
11156	53.4361	6.8638	1.0515	1.0450
11012	53.4401	6.8617	1.0515	1.0450
11236	53.4361	6.8638	1.0515	1.0450
11149	53.4361	6.8638	1.0515	1.0450
11155	53.4361	6.8638	1.0515	1.0450
11151	53.4361	6.8638	1.0515	1.0450
11150	53.4361	6.8638	1.0515	1.0450
11147	53.4361	6.8638	1.0515	1.0450
11148	53.4361	6.8638	1.0515	1.0450
11238	53.4361	6.8638	1.0515	1.0450
11239	53.4361	6.8638	1.0515	1.0450
501	53.4361	6.8638	1.0515	1.0450
11131	53.4247	6.8735	1.0515	1.0450
11170	53.1234	6.9497	1.0515	1.0450
401	53.4361	6.8638	1.0515	1.0450
801	53.4361	6.8638	1.0515	1.0450

Terminal	Latitude	Longitude	Voltage without electrolyser (p.u.)	Voltage with electrolyser (p.u.)
12036	53.2127	6.4784	1.0514	1.0440
16020	53.2127	6.4784	1.0514	1.0440
11215	53.2127	6.4784	1.0514	1.0440
11159	52.2488	6.7590	1.0504	1.0375

As it can be seen in Figure 4-4, when the electrolyser is connected, only in three terminals (Diele, Gronau and 15052) the voltage is above the 1.05 limit, while without the electrolyser the voltages at the 61 terminals are above the 1.05 limit.

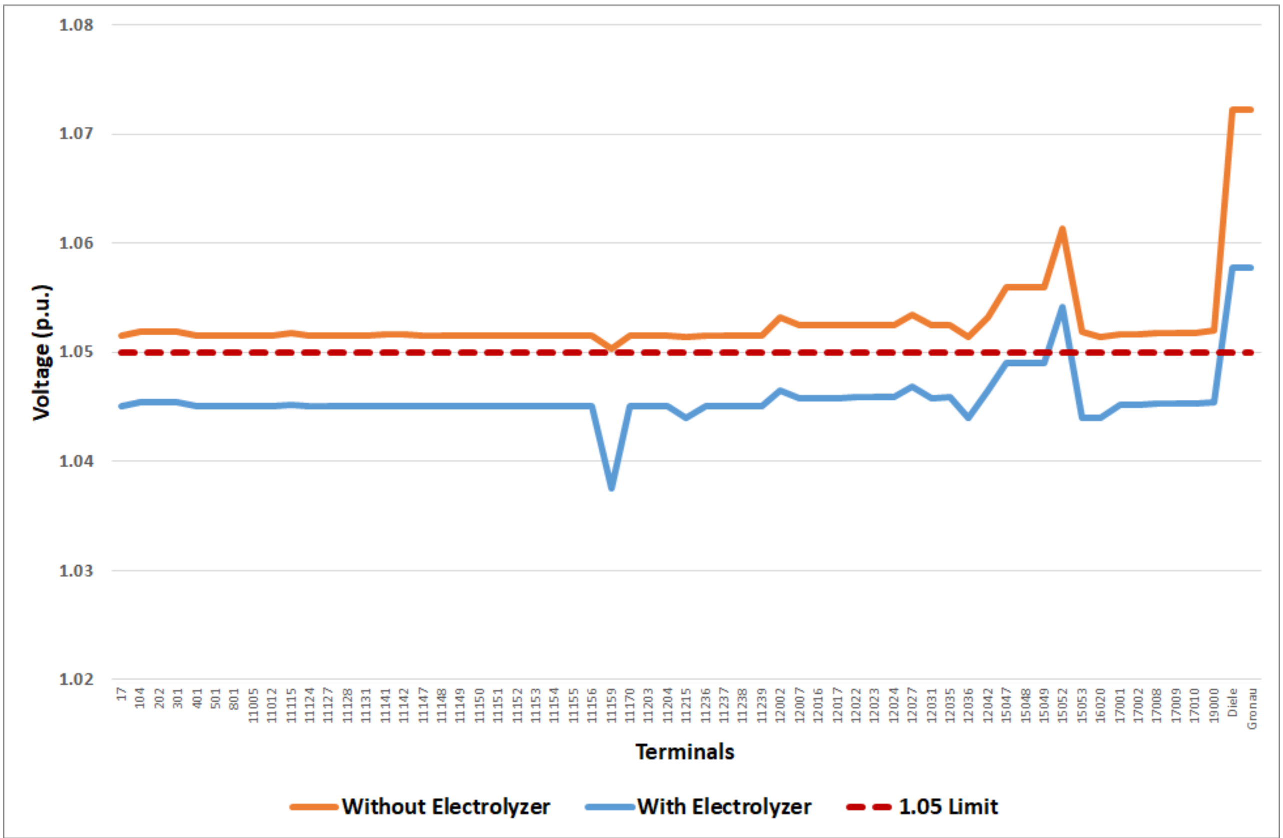

Figure 4-4. Network node voltage profile with/without electrolyser (source: CIRCE)

Since the analysis performed is a static one, dynamics from the electrolyser or the battery cannot be considered and are non-distinguishable. Therefore, the effect of the battery providing reactive support through adequate power electronics is the same as the effect of the electrolyser.

5 CONCLUSIONS

Contribution to local grid stability is defined in the context of this deliverable as: outcomes of the grid modelling that evaluate the effect on network congestions and on voltage stability in the Dutch transmission network through the operation of an electrolyser or battery.

To assess the effect on the relief of the congestions and the reduction of RES curtailment in the Dutch network due to the installation of an electrolyser or battery, the devised methodology is based on Optimal Power Flow analysis. Therefore, it is paramount to develop a network model of the area under analysis. This network model must comprehensively include and characterise all the elements comprising the power system and describe all their electrical parameters. The accuracy of the model impacts the accuracy of the results obtained from the analysis, and this is a limitation of the assessment performed.

On the other hand, to evaluate the separate effect of the electrolyser on the local voltage support, the grid model is reduced to focus on a smaller representation of the grid considering the network nodes in the vicinity of the electrolyser.

From the results, it can be seen that the electrolyser generally outperforms the battery in reducing the congestions for most of the scenarios considered (all save conservative) and developed in the Market Model (see report of Task 1). Congestion is reduced in a quantity ranging from 3.2 to 204 MW_{avg}/hour in the case of the electrolyser and from 0 to 326 MW_{avg}/hour in the case of the battery as shown in Table 4-2. However, both systems have a positive effect on the reduction of network congestion.

In the same vein electrolyser outperforms the battery in most of the investigated scenarios, although both systems have a beneficial impact, in the reduction of RES curtailment. Battery's ability to absorb power is limited by its state of charge, there is no such limitation in the electrolyser. As it can be seen from the results the more progressive a scenario is the higher the reduction of the RES curtailment. Reduction of RES curtailment for all scenarios are comprised between 0 a 34% for the electrolyser and inside the range from 0 to 25% for the battery.

In contrast, according to the analysis performed for the contribution to local voltage stability, the effects of the electrolyser and the battery are apparently the same. The assessment performed is a static analysis, which does not consider the different dynamics of the electrolyser and the battery. Therefore, the behaviour, as far as the evaluation carried out is concerned, is the same. Nevertheless, it has been proven qualitatively that having an electrolyser/battery located in Eemshaven is beneficial to keep node voltages inside the allowed limits through the provision of reactive power in case some voltage discursion/disturbance occurs.

The used model for this assessment is a static model lacking information on the dynamics of the power system assets. This is the main limitation to perform a more complete stability analysis. These results are complemented by the analyses performed in Activity 2.

NOMENCLATURE

AC	Alternating Current
AWF	Aggregated Wind Farms
CBA	Cost Benefit Analysis
DC	Direct Current
ENTSO-E	European Network of Transmission System Operators of Electricity
GDF	Groningen-Drenthe-Friesland region
GDOF	Groningen/Drenthe/Overijssel/Friesland
GSEE	Global Solar Energy Estimator
HTLS	High Temperature Low Sag
HVDC	High Voltage Direct Current
KPI	Key Performance Indicator
OPF	Optimal Power Flow
p.u.	per unit
P2G	Power-to-Gas
PCI	Project of Common Interest
REI	Radial, Equivalent and Independent
RES	Renewable Energy Sources
TSO	Transmission System Operator
TYNDP2018	Ten Year Network Development Plan 2018
VWF	Virtual Wind Farm