Potential cases for electrolysis as solution for grid congestion

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Management summary

- Due to higher electricity demand, increasing renewable generation and insufficient pacing of grid reinforcement, the Netherlands is facing increasing grid congestion[1]. Because of this increasing grid congestion many new renewable energy and electrification projects cannot be connected to the grid, which poses a barrier to the energy transition. Besides grid reinforcement, several solutions to solve grid congestion exist, such as electrolysis (as part of the demand side flexibility technologies). This means that for solving congestion, electrolysis competes with all these solutions, listed in the following picture:

Making use of redundant cables	Solar and wind on one grid connection	Combining assets behind the meter	Curtailment	Demand side flexibility technologies	Storage technologies

- Under specific conditions local electrolysis as solution for grid congestion can be economically feasible[2]:
  1. There must be sufficient local market potential for the produced hydrogen.
  2. The electricity price must be sufficiently low
  3. Additional incentives for congestion management should be provided
- Congestion management is used to steer assets when there is shortage of transport capacity. Congestion management can provide a financial incentive for electrolysers through redispatch-auctions or bilateral capacity limiting contracts[3].

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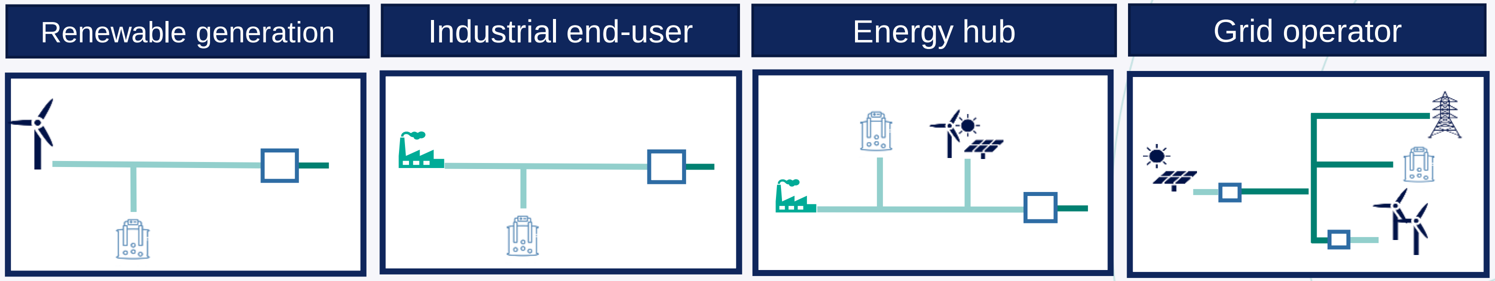
[1]Netbeheer Nederland (2021, 16 April) *Netbeheerders publiceren landelijke capaciteitskaart voor producenten duurzame energie.* Netbeheerders publiceren landelijke capaciteitskaart voor producenten duurzame energie - Netbeheer Nederland
[2] TNO (2018) Waterstof uit elektrolyse voor maatschappelijk verantwoord netbeheer – Businessmodel en businesscase.
[3]Staatscourant van het Koninkrijk der Nederlanden (2022) Besluit van de Autoriteit Consument en Markt van 24 mei 2022 kenmerk ACM/UIT/577139 tot wijziging van de voorwaarden als bedoeld in artikel 31 van de Elektriciteitswet 1998 betreffende regels rondom transportschaarste en congestiemanagement. Staatscourant 2022, 14201 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)

Management summary

- In this research, 4 cases of using electrolysis for congestion management have been evaluated on legal and market aspects and the impact on congestion problems, shown schematically below:



- From analysis of the four cases, the following conclusions can be drawn:
    - Economic feasibility of the electrolyser will depend strongly on the presence of a local hydrogen user.
    - Cases with renewable energy and industrial hydrogen demand nearby have highest potential to be a feasible case, so called energy hubs (case 3).
    - The case with the highest expected impact on congestion is when the electrolyser is owned and operated by the grid operator. This case also has the highest legal barrier, since the grid operator is not allowed to own or operate energy assets.
    - Congestion impact and business case do not necessarily go hand in hand. The operational strategy for economic benefit of the electrolysers can have a negative impact on the congestion problem.

Management summary

- This report covers background of grid congestion in the Netherlands and the evaluation of four use cases for electrolysis as solution for grid congestion.
- The background of grid congestion is aimed at readers who are looking for basic information regarding grid congestion and its solutions. covers the following topics:
  - The current state of grid congestion in the Netherlands, Page 6-7
  - An overview of the solutions for grid congestion, Page 8
  - Introduction into congestion management, and Page 9-10
  - A detailed description of the solutions for grid congestion. Page 11-16
- The case study for electrolysis as solution for grid congestion is structured as follows:
  - Boundary condition for economic feasibility Page 18
  - Introduction of the four case studies Page 19
  - Analysis of the specific case studies Page 20-23
  - Overview of the case study analysis Page 24
- These topics are followed by the conclusions which can be drawn from the case study analysis. Page 26

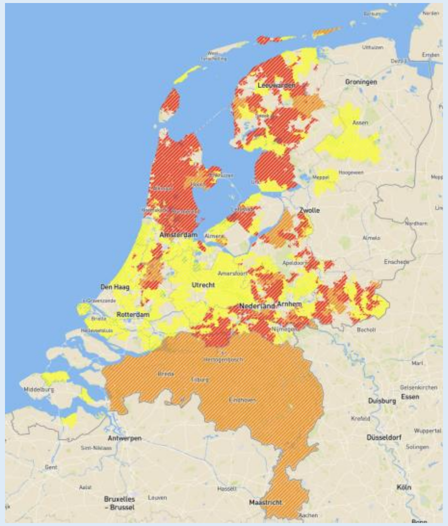
Background: grid congestion in the Netherlands

Grid congestion poses a barrier to the energy transition

- Definition by Netherlands Enterprise Agency (RVO):

  “Grid congestion occurs when the demand for transport capacity in the electricity grid (both for demand and supply) exceeds the transmission capacity of the grid. This means that the maximum amount of electricity that can be moved across the grid per quarter of an hour has already been reached.”

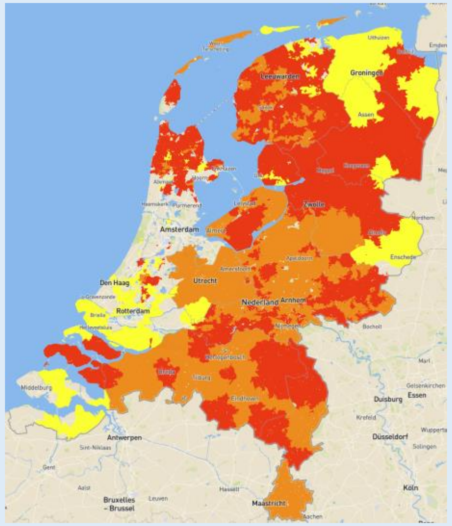
- According to the Dutch grid operators, there are **two main types** of congestion:



Demand-congestion:

Too much power is demanded from the grid simultaneously.

This map can be used by parties that plan a new electrical connection or want to expand their existing electrical connection.



Supply-congestion:

Too much electricity supplied to the grid simultaneously.

This map is meant for energy producers, that plan to deliver electricity into the grid. For SDE++ subsidies, the grid operator must provide a positive ‘transport indication’, which indicates transport capacity is available at that location.

- In **red** areas: applications for transport capacity are rejected or postponed by the grid operator.
- Because many new renewable energy projects cannot be connected to the grid, congestion poses a barrier to the energy transition.

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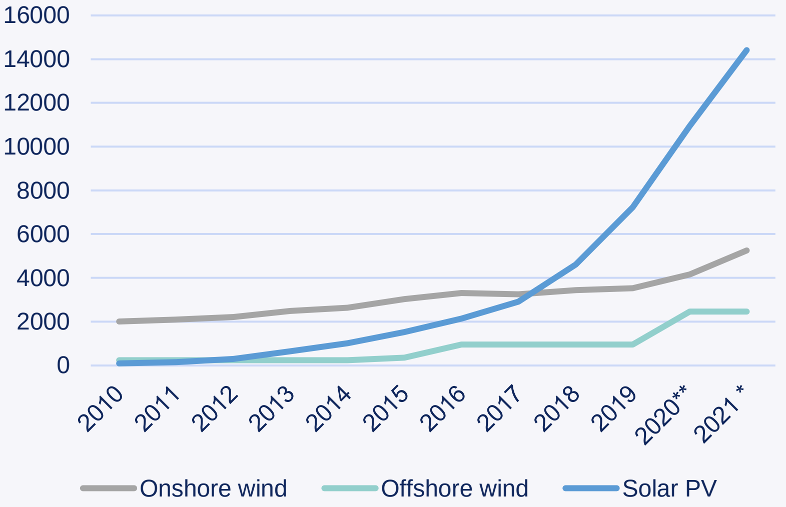
RVO (2021, 9 Sep) *Netcapaciteit en netcongestie*. Netcapaciteit en netcongestie (rvo.nl)
Netbeheer Nederland (2021, 16 April) *Netbeheerders publiceren landelijke capaciteitskaart voor producenten duurzame energie.* Netbeheerders publiceren landelijke capaciteitskaart voor producenten duurzame energie - Netbeheer Nederland
Images source: Netbeheer Nederland (2022) Capaciteitskaart elektriciteitsnet Capaciteitskaart elektriciteitsnet (netbeheernederland.nl)

Grid congestion is caused by a higher electricity demand, increasing renewable energy generation and insufficient pace of grid reinforcement.

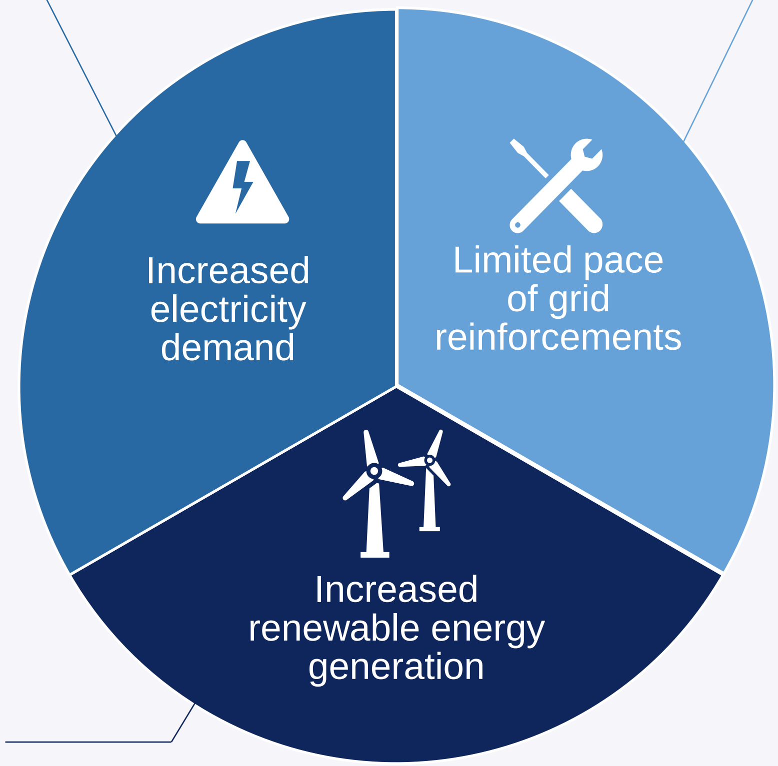
A **higher electricity demand**, which results from:

- Economic growth
- Increasing demand for housing
- Electrification of mobility (and expected in industry)

Increased installed capacity of solar & wind power (CBS, 2022)



*: provisional figure **: revised provisional figure



- **Shortage of technical staff**: The supply of technically skilled personnel cannot keep up with the increased demand due to the energy transition (Ecorys, 2021).
- **Financing**: Regional grid operators and TSO must invest heavily in the expansion of the electricity grid, which will be earned back through grid tariffs over a period of 40 years. To finance the needed investments, the regional grid operator and TSO must attract debt and equity capital.
  - The Dutch government is considering to contribute billions to help finance the expansion of the electrical grid (Rijksoverheid, 2022).
- **Long lead times for grid reinforcements**: Caused mainly by slow spatial procedures to obtain permits for new cables and stations. Grid reinforcements in the MV-grid take on average 5-10 years (CE Delft, 2021).
- **Scarcity of space in the Netherlands**: Obtaining space to realize new substations and cables is a growing challenge, which can take multiple years in extreme cases (CE Delft, 2022).

Sources:
Ecorys (2021) Klimaatbeleid en de arbeidsmarkt: Een verkennende studie naar de werkgelegenheidseffecten van CO2-reductiemaatregelen.
Rijksoverheid (2022) Kamerbrief stand van zaken financiering regionale netwerkbedrijven. Rijk is bereid miljarden in het stroomnet te investeren, in ruil voor een flinke v in de pap - NRC
CE Delft (2021) Doorlooptijden investeringen elektrificatie CE_Delft_200408_Doorlooptijden_Investeringen_Elektrificatie
CE Delft (2022) Het net slimmer benut. CE_Delft_210392_Het_net_slimmer_benut_DEF2.pdf
CBS (2022) Hernieuwbare elektriciteit; productie en vermogen. https://opendata.cbs.nl/#/CBS/nl/dataset/82610NED/table?dl=63EB5

Besides grid reinforcement, congestion can be solved by static and dynamic solutions

- Making use of redundant cables
- Solar and wind on one grid connection
- Combining assets behind the meter

Static solutions,
no change in demand & supply patterns

- Curtailment
- Demand side flexibility technologies
- Storage technologies

Congestion management

Dynamic solutions,
managing peaks in power supply and demand

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Congestion management is used to steer dynamic solutions when there is shortage of transport capacity.

Making use of redundant cables

Solar and wind on one grid connection

Combining assets behind the meter

Curtailment

Demand side flexibility technologies

Storage technologies

Congestion management

Description

Congestion management is a daily process where the regional and national grid operators solve local scarcity of transport capacity by requesting local electricity users or suppliers to change their expected production or consumption of electricity at a specific time in exchange for remuneration.

This can be organized through redispatch bids (on the GOPACS platform) or through bilateral capacity limiting contracts.

Legal:

Congestion management was already possible since 2012, but was not widely implemented by the regional grid operators. Since the publication of the modified grid codes in May of 2022 which enter into force by November of 2022, it is expected that more congestion management will be effectuated.

Result:

Due to congestion management, the scarce transport capacity is divided among the users of the grid. Congestion management is a temporary solution, until grid reinforcements can be realized.

Staatscourant van het Koninkrijk der Nederlanden (2022) Besluit van de Autoriteit Consument en Markt van 24 mei 2022 kenmerk ACM/UIT/577139 tot wijziging van de voorwaarden als bedoeld in artikel 31 van de Elektriciteitswet 1998 betreffende regels rondom transportschaarste en congestiemanagement. Staatscourant 2022, 14201 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)

Congestion management can provide a financial incentive for electrolysers through redispatch-auctions or bilateral capacity limiting contracts.

Making use of redundant cables | Solar and wind on one grid connection | Combining assets behind the meter | Curtailment | Demand side flexibility technologies | Storage technologies

Congestion management

Congestion management is organized through market- and non-market-based mechanisms. There are two main mechanisms for market-based congestion management:

- **Redispatch** bidding: The grid operator requests a congestion-order on the **GOPACS** platform. Locally connected parties with flexible electricity production, demand or storage can place responding bids on the platform. Bids are placed on the intraday-timeframe. Because this action may not disturb the balance in the grid, a compensating action is required, of the same size in the opposite direction and outside of the congestion area.
- **Capacity limiting contracts** are short- or long-term bilateral contracts between a grid operator and a grid-connected party. The latter commits to limiting their electricity supply or demand under specified conditions or upon request of the grid operator. These request are placed before the closure of the day-ahead market.

Non-market-based congestion management can only be used, when market-based mechanisms are insufficient.

Staatscourant van het Koninkrijk der Nederlanden (2022) Besluit van de Autoriteit Consument en Markt van 24 mei 2022 kenmerk ACM/UIT/577139 tot wijziging van de voorwaarden als bedoeld in artikel 31 van de Elektriciteitswet 1998 betreffende regels rondom transportschaarste en congestiemanagement. Staatscourant 2022, 14201 | Overheid.nl > Officiële bekendmakingen (officielebekendmakingen.nl)

Potential solutions for grid congestion

Making use of redundant cables	Cable pooling	Combining assets behind the meter	Curtailment	Demand side flexibility technologies	Storage technologies

Description
Redundancy (also known as ‘N-1’) means that the electricity grid is constructed in such a way that when there is a failure somewhere in the grid, there is an alternative route available. That way, a single failure never leads to an outage. Additionally, maintenance in the grid can occur without interrupting the power supply.
New electricity suppliers can be connected to this ‘emergency lane’ in the electricity grid. Grid operators maintain security of supply by temporarily switching of these grid connections during grid malfunctions and maintenance.

Legal:
Since a change in rules and regulations in 2021, it is possible for grid operators to connect new electricity suppliers above 6MVA to this ‘reserve capacity’ of the electricity grid.

Result:
Electricity suppliers or end-users on the waiting list for a grid connection can be connected earlier than planned, because of increased transport capacity in the grid. The grid operator has less redundancy in the grid, leading to a higher risk of outages for the assets connected by this method

Extra available transport capacity:

1 GW in the grid of Enexis

30% more in the TenneT grid.

Enexis (2021) Wetswijziging: Reservecapaciteit gebruiken voor energie-opwek. Nieuws | Wetswijziging: Reservecapaciteit gebruiken voor energie-opwek | Enexis Netbeheer
Liander (2019) Innovatieve flexoplossingen om congestie in het net te verminderen. Liander

Potential solutions for grid congestion

Making use of redundant cables	Cable pooling	Combining assets behind the meter	Curtailment	Demand side flexibility technologies	Storage technologies

Description
Cable pooling means that a wind and solar farm share one grid connection. This is effective, because their generation profiles are usually complementary. Therefore the capacity of the cable is used more efficiently.

Legal:
Since 2020, it is possible to connect both solar and wind behind one grid connection. When there are different proprietors of the solar and wind park, it is necessary to make use of the 'Meerdere leveranciers op één aansluiting' (MLOEA) construction. This requires more than one allocation point behind the meter.

Result:
More renewable energy generation can be connected with existing grid capacity, with slightly more curtailment of the produced electricity. Project developers save on grid costs and decrease waiting time. The grid operator saves on investment costs.

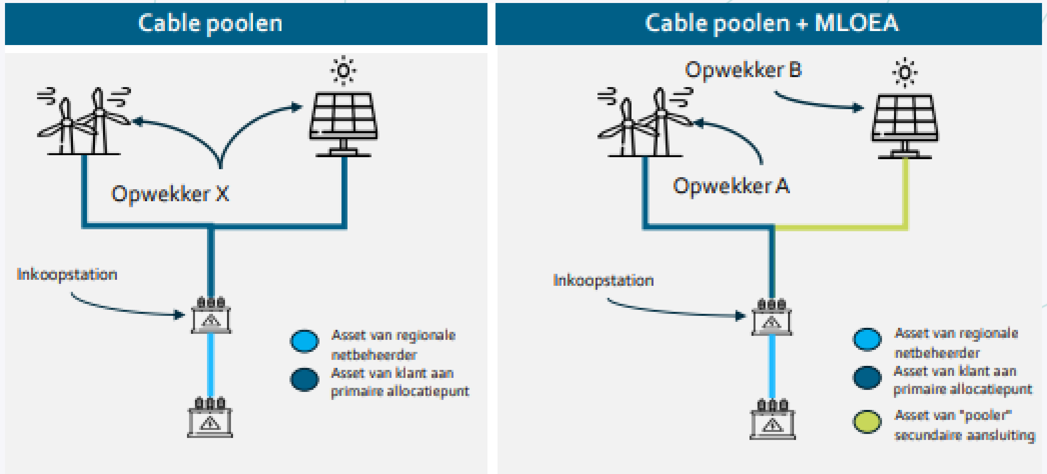

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Image source: Netbeheer Nederland [Maximaal benutten van capaciteit Cable pooling (netbeheernederland.nl)]

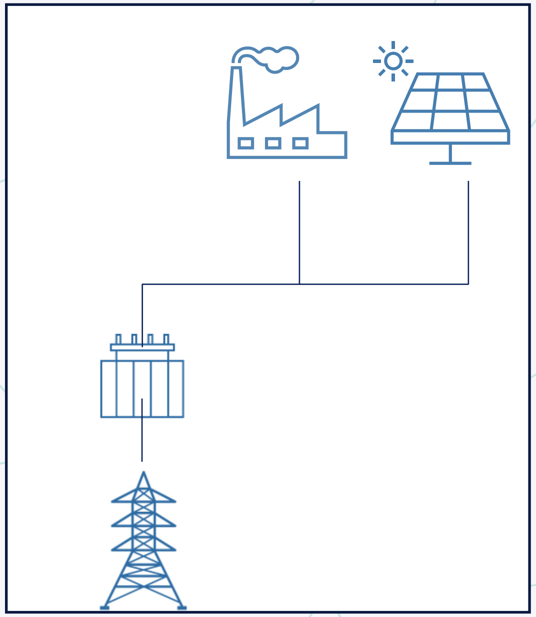
Potential solutions for grid congestion

Making use of redundant cables	Cable pooling	Combining assets behind the meter	Curtailment	Demand side flexibility technologies	Storage technologies

Description
When large scale renewable energy projects cannot be connected directly to the grid, it can be possible to connect them behind the meter of a large-scale electrical user with sufficient transport capacity.

Legal:
It is legally (and technically) possible, under certain conditions. There are multiple legal constructions that can be further explored:
- Direct line
- 'Gesloten Distributie Systeem' (GDS) or Closed distribution system

Result:
A new grid connection can be avoided altogether, which is advantageous for the grid operator and for the energy producer. Additionally, the overall electricity demand from and to the grid will decrease.



RVO (2021) Verbeteren netinpassing zonne-energieprojecten Verbeteren netinpassing zonne-energieprojecten (rvo.nl)

Potential solutions for grid congestion

Making use of redundant cables	Cable pooling	Combining assets behind the meter	Curtailment	Demand side flexibility technologies	Storage technologies

Description
Purposely reducing the amount of electricity generated by a solar or wind park to maintain balance between supply and demand, to avoid grid congestion or to respond to prices.

Legal:
It is legally possible to adjust power production for both through market- and non-market-based congestion management (see page 10 and 11) as well as in emergency situations.

Result:
When there is congestion, a solar or wind park can be curtailed. This causes lost revenue for the energy producer. If the solar of wind park has an agreement with the grid operator, grid investment can be postponed.

Royal HaskoningDHV (2021) Verbeteren netinpassing zonne-energieprojecten Verbeteren netinpassing zonne-energieprojecten (rvo.nl)
RVO (2022) SDE++ 2022 Stimulering Duurzame Energieproductie en Klimaattransitie. Brochure - SDE++ 2022_NL (rvo.nl)

Potential solutions for grid congestion

Making use of redundant cables	Cable pooling	Combining assets behind the meter	Curtailment	Demand side flexibility technologies	Storage technologies

Description
Demand side flexibility technologies can adjust their power demand. Because the electricity demand can be reduced or shifted in time, demand can be decreased during times when there is local demand-congestion, or demand can be increased when there is local supply-congestion. In general, the flexibility asset also has to be operated on other markets to be economically feasible (see page 16 for electrolysers).

Legal:
It is possible to adjust power demand for congestion management (see page 10 and 11).

Result:
Demand side flexibility technologies make use of produced electricity during times of congestion. If the flexibility asset has an agreement with the grid operator, grid investment can be postponed.

For example:
- Electrolysers
- Heat pumps
- Electric boilers
- EV Smart Charging

Potential solutions for grid congestion

Making use of redundant cables	Cable pooling	Combining assets behind the meter	Curtailment	Demand side flexibility technologies	Storage technologies

Description
Technologies that can store electricity temporarily. Thereby, electricity production and demand peaks can be shifted in time. For example, a battery can be placed next to a solar- or windpark and store part of the electricity during high production (peak shaving). The appropriate type and size of storage depend on the supply and demand profiles. In general, the storage asset also has to be operated on other markets to be economically feasible.

For example:
- Li-ion battery
- Redox flow battery
- Compressed air
- Vehicle to grid

Legal:
It is possible to use storage technologies for congestion management (see page 10 and 11).

Result:
Storage can store electricity during moments of congestion and deliver to the grid at a later moment. This has a benefit for the energy producer, as the electricity does not have to be curtailed. If the storage asset has an agreement with the grid operator, grid investment can be postponed.

4 Cases:
Electrolysis to reduce grid congestion

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Electrolysis for congestion management is economically feasible under specific conditions.

- Case studies by TNO & Enpuls (2018) have shown that the use of electrolysis for congestion management can be feasible in specific situations.
- The two most important prerequisites for a positive business case:
  1. **There must be sufficient local market potential for the produced hydrogen**.
     - Local use and willingness to pay must be enough to cover the costs of the electrolyser
     - Local use is important, because it keeps the transport cost low.
  2. **The electricity price must be sufficiently low**
     - In all studied cases, the business case only works if the electrolyser operates (almost) continually.
     - The marginal cost of hydrogen production are proportional to the electricity price

TNO (2018) Waterstof uit elektrolyse voor maatschappelijk verantwoord netbeheer – Businessmodel en businesscase.

Evaluation of 4 cases of using electrolysis for congestion management

Making use of redundant cables	Cable pooling	Combining supply and demand behind the meter	Curtailment	Demand side flexibility technologies	Storage technologies

- **Electrolysers**
- Heat pumps
- Electric boilers
- EV Smart Charging

4 electrolyser cases:

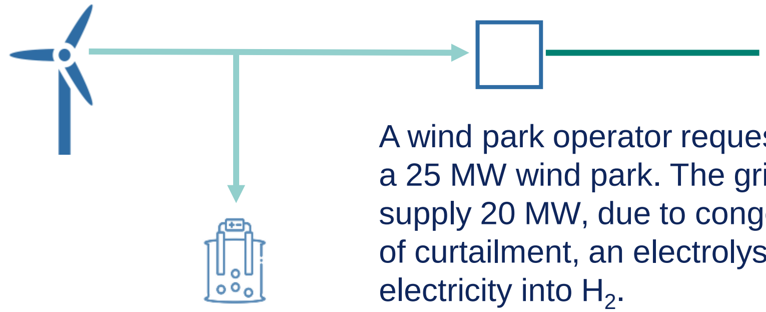
1. Renewable generation
2. Industrial end-user
3. Local energy hub
4. grid operator operated

Evaluated on:

- TRL of flexible operation
- Congestion impact
- Legal aspects
- Operational strategy
- Willingness to pay
- Market size (H_2)

Case 1: Electrolyser in combination with renewable generation

Case description



A wind park operator requests a grid connection for a 25 MW wind park. The grid operator can only supply 20 MW, due to congestion in the grid. Instead of curtailment, an electrolyser converts the excess electricity into H_2.

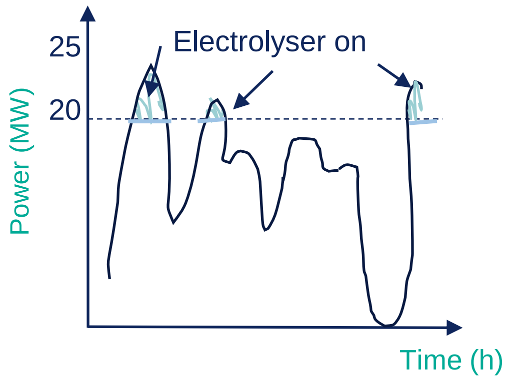
Legal aspects

- Cable pooling is not applicable.
- Definition: is it a grid ('net'), a direct line or an installation? This is dependent on the types of connections and whether the energy and H_2 producer are the same legal entity.
    - Direct line between wind energy producer and electrolyser cannot have a direct connection to the grid.
- It is also possible to enter into a capacity limiting contract with the grid operator to ensure the electricity supply to the grid remains below 20 MW. If the assets are owned by different proprietors, this can be arranged by a Congestion Service Provider (CSP).

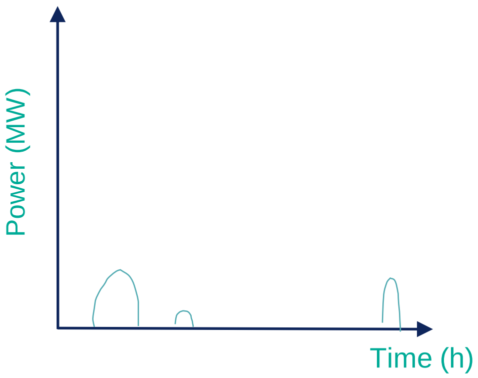
Electrolyser operation:

- Minimum for congestion: electrolyser turns on when wind power exceeds 20MW.

Wind power generation



Electrolyser power consumption



- For economic feasibility: bilateral agreement on price. Higher utilization of electrolyser.

What is the value of this case for the different stakeholders?

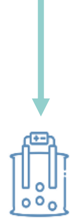
H_2 producer	Use cheap green electricity to produce H_2 when there is congestion.
Energy producer	Sell all electricity, instead of curtailment.
Grid operator	Postpone investment in grid reinforcement
Society	More wind/solar parks connected. Utilization of green electricity that was otherwise lost.

Readiness:

Technical (TRL): Medium
Legal: Medium-High
Hydrogen market size: Low-High (dependent on local H_2 demand)
Willingness-to-pay: Low-High (dependent on local H_2 demand)

Case 2: Electrolyser in combination with an industrial end-user

Case description



An industrial user has a constant H_2 demand and wants to produce its own H_2. It needs more transport capacity to connect a 5 MW electrolyser but the grid operator cannot provide extra capacity due to demand congestion.

Legal aspects

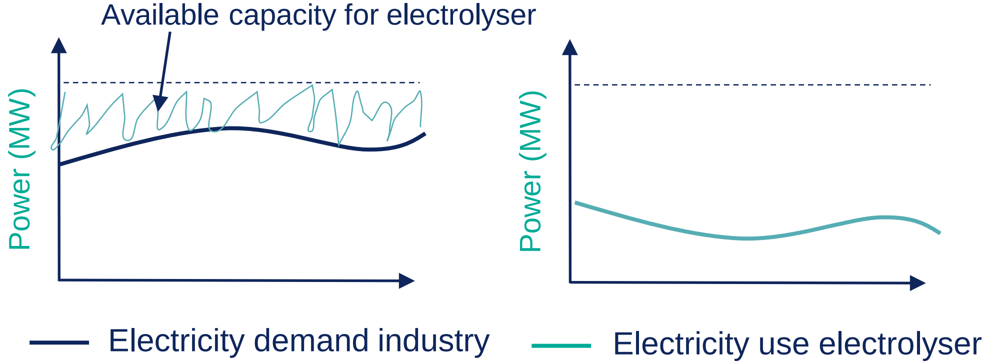
- Definition: is it a grid ('net') or an installation? Dependent on types of connections and whether the energy and H_2 producer are the same legal entity.
    - Installation is easier to realize than grid.
- Direct line is not applicable.
- Located in congestion area? In principle, you must wait your turn on the waiting list until you can be connected. If the electrolyser can be connected, it is possible to provide congestion management services through capacity limiting contracts.

Electrolyser operation:

Electrolyser doesn't work at full capacity, but only uses the available capacity on the grid connection.

If industry has a constant H_2 demand, storage is necessary or the remaining H_2 is bought on the market.

Industrial electricity demand **Electrolyser power consumption**



What is the value of this case for the different stakeholders?

H_2 producer	Sell H_2 to local industry. Possibility to connect due to flexible operation.
Industrial party	Supply of local H_2 , H_2 with electricity from the grid may not be green.
Grid operator	None
Society	None, on short term.

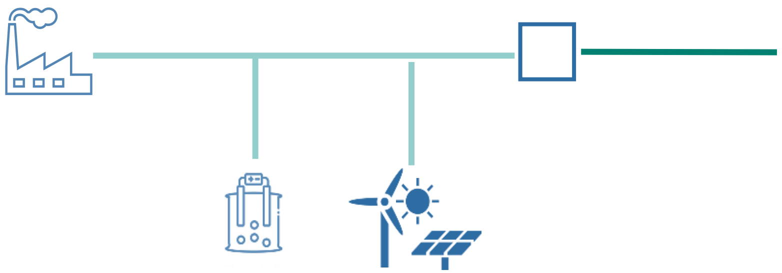
Readiness:
Technical (TRL): High
Legal: Low-High
Hydrogen market size: High
Willingness-to-pay: Medium (Industry) – High (Mobility)

Case 3: Local energy hub

Case description

In an energy hub, energy generation, use, conversion and/or storage are combined behind the meter. There are two options for congestion problems:

- Due to increased generation of on-site green electricity, large amounts of electricity needs to be delivered back into the grid, which is not possible due to supply congestion. Solution: instead of curtailment, convert excess power into hydrogen.
- Due to increased electricity demand from industry, including an electrolyser, large amounts of electricity needs to be supplied from the grid, which is not possible due to demand congestion. Solution: Electrolysers operates flexibly within limits of the congestion problem.



Electrolyser operation:

- For congestion: Convert the electricity that exceeds the maximum capacity that may be delivered back into the grid or only use the electricity for hydrogen within the maximum capacity. Use hydrogen storage to meet the industrial demand.
- For economic feasibility: turn the electrolyser on during favorable moments (dependent on bilateral agreements with solar/wind park and electricity prices), use hydrogen storage to meet the industrial demand.

Legal aspects

- Definition: is it a grid ('net'), a direct line or an installation? Dependent on types of connections and whether the energy and H_2 producer are the same legal entity.
  - Direct line: If wind is specifically only for industrial user and hydrogen production.
  - Otherwise, one should make use of GDS structure. Large-scale industrial users often already have a GDS in place.
- The local energy hub can enter into a capacity limiting contract with the grid operator, to provide aggregated flexibility via a Congestion Service Provider (CSP).

What is the value of this case for the different stakeholders?

H_2 producer	Sell H_2 to local industry. Possibility to connect due to flexible operation. Use cheap green electricity when there is congestion
Energy producer	Sell all electricity, instead of curtailment.
Grid operator	Possibility to postpone or avoid investment in grid reinforcement. If GDS or direct line: not involved. Risk: together the assets must keep within the boundaries of transport capacity.
Industry	Supply of local H_2 , H_2 with electricity from the grid may not be green.
Society	More wind/solar parks connected. Utilization of green electricity that was otherwise lost.

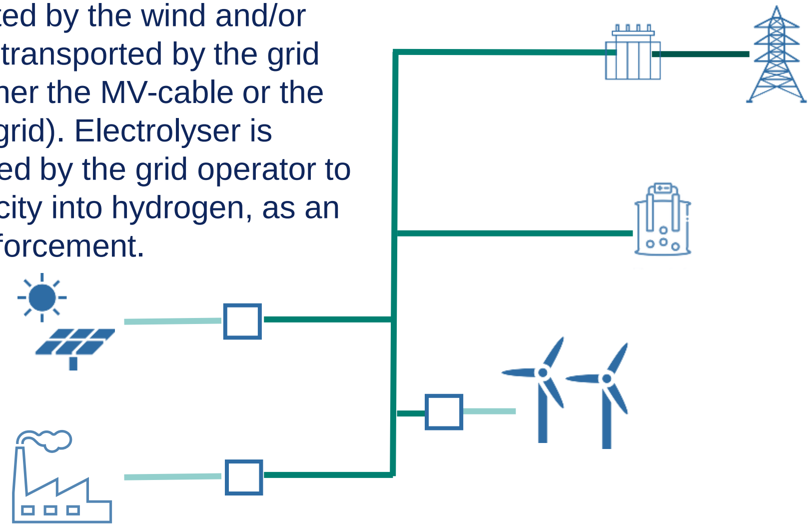
Readiness:

Technical (TRL): High
Legal: Medium-High
Hydrogen market size: High
Willingness-to-pay: Medium-high

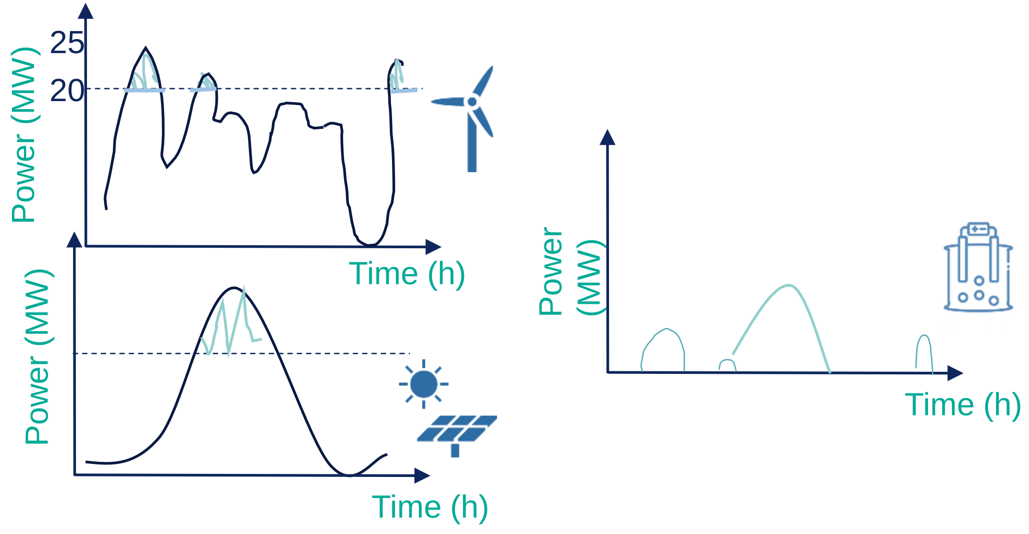
Case 4: Electrolyser operated by grid operator for congestion management

Case description

The electricity generated by the wind and/or solar parks cannot be transported by the grid due to congestion (either the MV-cable or the connection to the HV-grid). Electrolyser is connected and operated by the grid operator to convert excess electricity into hydrogen, as an alternative to grid reinforcement.



Electrolyser operation:



Legal aspects

- Legally a grid operator is not allowed to own and operate energy assets. A grid operator may only transport energy, not generate, convert or trade energy.

What is the value of this case for the different stakeholders?

H_2 producer	Get a fee for producing hydrogen when there is an excess of local green electricity.
Energy producer	No curtailment
Grid operator	Avoid grid reinforcement.
Industry	Local green H_2
Society	More wind/solar parks connected. Utilization of green electricity that was otherwise lost.

Readiness:

Technical (TRL): Medium
Legal: Low
Hydrogen market size: Low-High
Willingness to pay: Medium-High

Cases overview

- The analysis of the four cases on technological (TRL), legal, hydrogen market size, hydrogen willingness to pay and congestion aspects is summarized in the following table:

	Renewable generation	Industrial end-user	Local energy hub	Grid operator
TRL	Medium	High	High	Medium
Legal	Medium-High	Low-High	Medium-High	Low
Market size (H_2)	Low-High	High	High	Low-High
Willingness to Pay (H_2)	Low-High	Medium-High	Medium-High	Medium-High
Congestion Impact: postpone or avoid grid reinforcement?	Postpone	No	Postpone	Avoid

Conclusion

Conclusions

- **Cases with renewable energy and industrial hydrogen demand nearby have highest potential to be a feasible case.** The economic feasibility of these cases depends on the demand of hydrogen and incentives for providing congestion management services.

- **The case with the highest expected impact on congestion is when the electrolyser is owned and operated by the grid operator.** This case also has the highest legal barrier, since the grid operator is not allowed to own or operate energy assets.

- **Congestion impact and business case do not necessarily go hand in hand.** If a third party would operate the electrolyser solely for congestion management, the main barrier will likely be the business case. The case where only industrial demand is available near the electrolyser has no or even a negative impact on local grid congestion. However, this can be a feasible case from an economic viewpoint.

- **Economic feasibility will depend strongly on the presence of a local hydrogen user.** The business case is only feasible if there is sufficient local demand for hydrogen, combined with an adequate willingness to pay.

Potential cases for electrolysis as solution for grid congestion

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