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PROPOSAL ON BALANCING THE DANISH HYDROGEN TRANSMISSION NETWORK

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Executive summary

With the implementation of a future hydrogen transmission network in Denmark, it is vital to outline and describe the overall market framework for the hydrogen transmission system. A key element in the market framework is how to effectively balance the hydrogen transmission network. This paper describes Energinet's proposal on principles for balancing a future hydrogen transmission network.

Physical limitations and legal framework conditions set the boundaries and/or opportunities for the design of a hydrogen balancing model. European and national legislation assign the role of designing, operating, and developing the hydrogen transmission network to Energinet. The legislative articles govern Energinet to foster the development of fair, non-discrimination, and transparent balancing rules. Furthermore, the articles demonstrate that the Network Users of the transmission network are responsible for balancing their balancing portfolios (deliverables and offtakes), to minimize the need for the TSO to undertake balancing actions. In addition to the legal boundaries, the physical limitations in a hydrogen transmission network have shown to be more flexible than an electricity transmission network but also more stringent than a natural gas system. Hence, the TSO must possess TSO balancing actions to restore the system state if it is jeopardized.

The balancing model is subject to change over time as the market develops and with the expected introduction of a network code on balancing.

The objective of the hydrogen balancing model is to allow for large quantities of hydrogen transportation, while accommodating the demand from the Network Users for a flexible utilization of the Hydrogen Network. The proposed balancing model is designed in such a way that each Network User is allocated their own Designated Linepack Flexibility (DLF) conditioned on their booked capacity, while they can also utilize the residual of the System Linepack Flexibility (SLF), which is available to all Network Users.

The Network User is equipped with multiple balancing mechanisms, yielding a foundation for proactive balancing of their own portfolio. Network Users causing the Accumulated System Balance (the accumulated balance of all Network Users) to cross its threshold will induce Energinet to activate TSO balancing actions to maintain the system balance. These Network Users are referred to as Causers. The costs of activating the TSO balancing actions will be allocated to the Causers. The TSO balancing actions consists of commercial and non-commercial balancing actions respectively. If commercial balancing actions are not available, prioritized cut-off is activated.

The prerequisite for flexible operation of the Network User's portfolio is knowledge on concrete price signals. Hence, an optimal coupling between the electricity market and the hydrogen market constitute to the foundation for utilizing the hydrogen transmission network.

Content

1. Introduction

This paper describes Energinet's proposal on principles for balancing a future hydrogen transmission network (hereafter referred to as Hydrogen Network) as part of the maturation of the Danish Hydrogen Backbone. This paper on balancing the Hydrogen Network is a sub paper to a paper on the market framework for the Hydrogen Network. The paper on the market framework will among other things entail a description of the expected entry-exit system and a description of the different roles on the hydrogen market. The market framework paper is scheduled to be published in September 2024 as part of information package 2.

This paper begins with an introduction to the key principles determining the direction for designing the balancing model. Then followed by a short description of the balancing model and how the balancing model will develop over time. Afterwards follows a chapter on the legal framework for the balancing model and on the physical limitations of the Hydrogen Network, respectively. The following chapters dive into specific aspects of the balancing model.
It should be noted that the balancing model will evolve over time, thus, an overall cautionary note is that the balancing model will start off being somewhat simple, though to some extent still reflecting the elements described in this paper.

Principles for the balancing model

The balancing model is an essential part of the market model and framework for using the future Hydrogen Network. The ability of the Hydrogen Network to transport hydrogen from entry-points to exit-points depends on a variety of physical parameters being within specific limits, including that the deliveries and offtake of hydrogen to/from the system is in balance over time.

Energinet's objective is to design a balancing regime, encompassing the balancing rules for the Hydrogen Network. Energinet has formulated a list of main principles, acting as guidelines for the development of the balancing model. The principles are partially governed by the EU-framework.

- The Network Users[1] are responsible for balancing their deliveries and offtake and thereby minimizing the need for the TSO to undertake balancing actions (residual balancing). Hence, the Network Users should be able to manage their own balance position based on high-resolution data collection on metering points.
- Energinet is responsible for the continuous physical balancing of the Hydrogen network, yielding activation of TSO balancing actions when needed.
- TSO balancing actions shall to the extent possible be market-based and rely on objective criteria.
- The balancing model shall live up to the criterion of being non-discriminatory, objective, and transparent.
- The balancing model is subject to change over time as the market develops and with the expected introduction of a network code on balancing. Thus, the balancing model must be scalable.

The aim of the model is to find the balance between utilizing the flexibility of the system, and still being able to operate the system in a secure way.

[1] The definition of a Network User follows in the section on EU legal framework.

The balancing model in brief

It is necessary to define the role of who is responsible for balancing deliveries and offtake in the Hydrogen Network. The EU-legislation (the hydrogen and gas markets decarbonisation package) defines two user-roles related to the Hydrogen Network: System Users and Network Users.

- System Users are defined as a natural or legal person supplying to, or being supplied by, the system.
- Network Users are defined as a customer or a potential customer of a system operator, and system operators themselves in so far as it is necessary for them to carry out their functions in relation to transport and balancing of hydrogen.

All articles regarding balancing in the EU regulation on hydrogen and gas refers to Network Users. Hence, this is the term that will be used in this paper. All applied definitions are described in chapter 9.

Respecting the principles for the balancing model, the proposed balancing model is designed in such a way that each Network User is allocated their own Designated Linepack Flexibility (DLF) while they can also utilize the residual of the System Linepack Flexibility (SLF), the non-Designated Linepack Flexibility (non-DLF). The balancing model for hydrogen consists of the following elements:

- An **Accumulated Network User Balance (ANUB)** illustrates the accumulated balance position of the Network User. The difference over time between a Network User's deliveries and offtakes of hydrogen in the Hydrogen Network equals the Network User's ANUB.
- An **Accumulated System Balance (ASB)** illustrates the accumulated balance of all Network Users. Thus, ASB equals the sum of all Network Users' ANUBs.
- A **Designated Linepack Flexibility (DLF)** is the amount of flexibility the individual Network User is allocated based on capacity bookings. The DLF is subject to secondary trade between Network Users.
- A **non-Designated Linepack Flexibility (non-DLF)** is the amount of flexibility that is not allocated to any Network User. Non-DLF can be used by Network Users collectively.
- A **System Linepack Flexibility (SLF)** is the total amount of Linepack Flexibility that can be used by the Network Users. Some of the SLF is used for allocation of DLF to the Network Users. The SLF is the sum of all the DLF and non-DLF. Hence, the SLF must always be greater than or equal to the sum of the DLFs.

In the proposed balancing model for hydrogen, the Network Users are responsible for balancing their deliveries and offtakes. The Network Users are expected to deploy own instruments to keep their portfolio in balance and avoid the ASB exceeding the boundaries of the SLF.

In addition, Energinet intends to facilitate instruments which the Network Users can use to balance their portfolio. For the residual balance, TSO balancing actions are presented which can restore any imbalances that might arise, when the boundaries for the SLF are exceeded.

Development of the hydrogen market over time

The matureness of the hydrogen market and the value chains surrounding the Hydrogen Network will evolve over time. Furthermore, a network code on balancing is expected in the future which will govern the framework for the balancing model. This demands the balancing model to be configurable and scalable. In Table 1 below, the key characteristics of an immature and mature market are outlined, and how Energinet expects the two different stages will be reflected in the balancing model.

Immature market	Mature market
• Energinet foresees an initialization of the hydrogen market and associated value chains with few market players and low utilization of the infrastructure's total capacity. • Platform for Network Users to trade commodities, i.e. hydrogen or DLF, are evaluated to have low to no utilization. • Energinet expects that commercial TSO balancing actions cannot be activated (there is no critical mass of Network Users willing to offer balancing services), yielding that cut-off deployment of imbalance-inducing Network users is the only tool for the TSO.	• The hydrogen market has reached a critical mass of Network Users, enabling the TSO to procure balancing services via cost-effective procurement methods to mitigate system imbalances. • Platform for Network Users to trade various commodities, i.e. hydrogen or DLF, are evaluated to be largely utilized. • As the number of Network Users increase, a development could be foreseen where dedicated Network Users become responsible for balancing multiple Network Users within the balancing zone, as known from balancing markets for electricity and gas. Third party players could also become part of the balancing market as Network Users, only concentrating on balancing.

Table 1: Key characteristics for an immature and mature market.

2. Legal framework

Energinet is responsible for designing, operating, and developing the future Hydrogen Network. The regulatory framework conditions set out by the EU and the Danish legislation must be respected. Hence, it is vital to outline and describe the relevant legislation associated to balancing a Danish and European Hydrogen Network. The below two sections describe the important aspects from the EU and Danish legislation.

This proposal on balancing the Hydrogen Network has been drafted based on the best available knowledge on the upcoming rules and regulations and this proposal should therefore be read under the condition that there may be material changes in the final rules and regulations. The final EU-regulation may include minor changes. The implementation of the directive in Danish law may include national decisions, which could influence the hydrogen balancing proposal. The balancing model could also be subject to changes due to an upcoming network code.

2.1 EU legislation

The European Union has drafted common European legislation for the hydrogen markets in an amended Gas Market Regulation and Gas Market Directive, which is expected to be implemented in the Danish Gas Supply Act[2]. This legislation sets rules and principles on methodologies for balancing. The following go-through highlights the articles of the amended EU regulation and EU directive and applicable legislation in the Danish Gas Supply Act, which are relevant for the balancing of Hydrogen Networks.

Relevant articles regarding balancing from the EU Regulation
Article 3 of the EU Regulation sets general principles for the hydrogen markets:

> *"Member States, regulatory authorities designated pursuant to Article 76 of Directive (EU) 2024/…+ (the 'regulatory authorities'), natural gas system operators, hydrogen system operators and delegated operators such as market area managers or booking platform operators shall ensure that markets for natural gas and hydrogen are operated in accordance with the following principles:*
>
> *[…]*
>
> e) *network users shall be responsible for balancing their balancing portfolios in order to minimise the need for transmission system operators and hydrogen transmission network operators to undertake balancing actions;*
>
> f) *balancing actions shall be performed on the basis of standardised products in accordance with the network code on balancing established pursuant to this Regulation and conducted on a trading platform or by means of balancing services in accordance with that network code;*
>
> *[…]*
>
> h) *market rules shall ensure a consumer-centred and energy efficient approach in the markets for natural gas and hydrogen;*

[2] Gasforsyningsloven (retsinformation.dk)

i) market rules shall ensure a consumer-centred and energy efficient approach in the markets for natural gas and hydrogen;

[…]

k) market rules shall deliver appropriate investment incentives, in particular for long-term investment in a decarbonised and sustainable system for natural gas and hydrogen, for energy storage, energy efficiency, demand reduction and demand response to meet market needs and system integration needs, and shall facilitate fair competition and security of supply, while implementing the energy efficiency first principle in avoiding investment incentives that lead to stranded assets;

[…]

m) barriers to cross-border natural gas and hydrogen flows, if existing, between entry-exit systems shall be removed;

n) market rules shall facilitate regional cooperation and integration."

Article 13 of the EU Regulation outlines the general balancing rules and imbalances charge guidelines:

"1. Balancing rules shall be designed in a fair, non-discriminatory and transparent manner and shall be based on objective criteria. Balancing rules shall reflect genuine system needs considering the resources available to the transmission system operator. Balancing rules shall be market-based.

2. In order to enable network users to take timely corrective action, the transmission system operator shall provide sufficient, timely and reliable on-line based information on the balancing status of network users.

The information provided shall reflect the level of information available to the transmission system operator and the settlement period for which imbalance charges are calculated.

No charge shall be levied for the provision of information pursuant to this paragraph.

3. Imbalance charges shall be cost-reflective to the extent possible, whilst providing appropriate incentives on network users to balance their input and off-take of natural gas. They shall avoid cross-subsidisation between network users and shall not hamper the entry of new market entrants.

Any calculation methodology for imbalance charges as well as the final values shall be made public by the regulatory authorities or the transmission system operator, as appropriate.

[...]"

The responsibilities of the Network Users in relation to balancing of the hydrogen infrastructure are stipulated in Article 3(e) of the EU Regulation, where the Network Users shall be responsible for balancing their portfolio.

Article 13(1) of the EU Regulation requires balancing rules to be fair, non-discriminatory, market-based and based on objective criteria. Furthermore, the regulation text requires high-resolution, online-based data on entry/exit points in the infrastructure, for the Network Users to perform proactive balancing.

This underlines the fact that the Network Users must be equipped with enough mechanisms to balance their own portfolio. In addition, the TSO is required to design and deploy TSO balancing actions if the Network User(s) fail to perform self-balancing.

The balancing regime is expected to be regulated in detail through a future EU network code with a legal basis in article 71(2)(c) in the EU Regulation:

> *"2. The Commission may adopt implementing acts establishing network codes in the following areas:*
> *[…]*
> *c) balancing rules including network-related rules on nomination procedure, rules for imbalance charges and rules for operational balancing between transmission system operators' systems implementing Articles 8 to 11 of this Regulation and Article 39(5) of Directive (EU) 2024/…+ including network-related rules on nomination procedures, imbalance charges, settlement processes associated with the daily imbalance charge and operational balancing between transmission system operators' networks;"*

Relevant articles regarding balancing from the EU Directive

Article 37 in the EU Directive sets out the rules for access to hydrogen storage, including access to linepack:

> *"1. Member States shall ensure the implementation of a system of regulated third-party access to hydrogen storage and, when technically and economically necessary for providing efficient access to the system for the supply of customers, access to linepack, as well as for the organisation of access to ancillary services based on published tariffs and applied objectively and without discrimination between any hydrogen system users. Member States shall ensure that those tariffs, or the methodologies underlying their calculation, are approved by the regulatory authority prior to their entry into force in accordance with Article 78.*
>
> *2. Until 31 December 2032, a Member State may decide not to apply paragraph 1. In such case, the Member State shall ensure the implementation of a system of negotiated third-party access to hydrogen storage and, when technically and economically necessary for providing efficient access to the system for the supply of customers, access to linepack, as well as for the organisation of access to ancillary services, in accordance with objective, transparent and non-discriminatory criteria. The regulatory authorities shall take the necessary measures for hydrogen storage users to be able to negotiate access to hydrogen storage and to ensure that the parties are obliged to negotiate access to hydrogen storage in good faith.*

3. Member States may provide for capacity rights allocated before … [2 years from the date of entry into force of this Directive] under a system of negotiated third-party access pursuant to paragraph 2 to be respected until their date of expiry and for them not to be affected by the implementation of a regulated third-party access pursuant to paragraph 1.”

The article stipulates that as a starting point system operators should provide access to the Hydrogen Network by regulated third party access (in contrary to negotiated access). The member state may decide to not apply this up to 2033. Changes should be expected to Section 20 a in the Danish Gas Supply Act (negotiated access to linepack).

Article 50(1) in the EU Directive sets out the tasks of the Hydrogen Network Operator. These tasks include the requirements for operating, maintaining, and developing the network and ensuring the long-term ability to meet the demand for transport:

“1. Each operator of hydrogen networks, storage or terminal shall be responsible for:

a) operating, maintaining and developing, including repurposing, under economic conditions a secure and reliable infrastructure for hydrogen transport or storage with due regard to the environment, in close cooperation with connected and neighbouring hydrogen network operators in order to optimise co-location of production and use of hydrogen and on the basis of the ten-year network development plan referred to in Article 55;

b) ensuring the long-term ability of the hydrogen system to meet reasonable demands identified for the transport and storage of hydrogen in accordance with the ten-year network development plan referred to in Article 55;”

Article 50(4) in the Gas Directive stipulates that Energinet shall be responsible for balancing in its Hydrogen Network from 1 January 2033 or earlier if required by the Danish Utility Regulator:

“4. Hydrogen network operators shall be responsible for balancing in their networks as from 1 January 2033, or as from an earlier date where so provided by the regulatory authority. […]”

Article 50(4) in the EU Directive stipulates that the hydrogen operator shall adopt balancing rules based on objective, transparent and non-discriminatory terms:

“4. Hydrogen network operators shall be responsible for balancing in their networks as from 1 January 2033, or as from an earlier date where so provided by the regulatory authority. Rules adopted by hydrogen network operators for balancing the hydrogen network shall be objective, transparent and non-discriminatory, including rules for the charging of users of their networks for energy imbalance.”

Article 78(7)(c) in the EU Directive stipulates that the regulatory authority shall fix or approve the methodologies developed by the TSO’s on balancing services:

“7. The regulatory authorities shall be responsible for fixing or approving sufficiently in advance of their entry into force at least the methodologies used to calculate or establish the terms and conditions for:

[…]
(c) the provision of balancing services to be performed in the most economic manner, to provide appropriate incentives for network users to balance their input and off-takes in a fair and non-discriminatory manner and to be based on objective criteria;"

2.2 National legislation

Hydrogen was more generally adopted in the Danish Gas Supply Act in December 2022 and in general, the "gas" provisions in the legislation now covers both gasses in the natural gas system and the Hydrogen Network. The amended EU Directive is expected to be implemented in the Danish Gas Supply Act which means the applicable legislation stipulated below may be subject to amendment.

Relevant sections from the applicable Danish Gas Supply Act (indicative translation)

Section 12(1)(7) in the Danish Gas Supply Act stipulates that the TSO shall ensure that there are financial incentives for system users to maintain the balance in the system:

"Section 12. A transmission company, a transmission system owner and a system operator shall:
[…]
7) ensure that there are financial incentives for system users to maintain the balance of the company's transmission system without interference pursuant to number 6, cf. section 20 and 36a; [number 6 refers to a safe physical balance of the system; § 36a refers to prices and conditions]"

Hence, the balance model for hydrogen should be designed in a way, that enables the Network Users to balance their portfolio to the extent possible. The design of the balancing model should be designed so marked-based tools are deployed as a priority.

Section 20 a in the Danish Gas Supply Act stipulates that access to storage and linepack are done through negotiated access:

"Section 20 a. Access to storage facilities, linepack, and other auxiliary services are offered by storage and transmission companies or transmission system owners and system operators through negotiated access, including through auction, based on objective, transparent, and non-discriminatory criteria. The provision includes all storage facilities in Denmark and all linepack and other auxiliary services in the transmission system"

Changes should be expected to this section as the EU Directive Article 37 are to be implemented in Danish law.

The balancing methodologies developed by Energinet are to be approved by the Danish Utility Regulator before entering into force, cf. section 36 a(1) in the Danish Gas Supply Act:

"Section 36 a. Prices and conditions for use of transmission systems and distribution systems and LNG-facilities are determined by transmission companies, transmission system owners, system operators and distribution- and LNG-companies under public methodologies which are approved by the Danish Utility Regulator."

3. Physical limitations of the Hydrogen Network

The physical limitations and constraints of the Hydrogen Network constitute the overall design framework for the balancing model.

In case of an incident, simulations have shown that the Hydrogen Network must be restored within a few hours. Thus, the Hydrogen Network must be balanced based on high-resolution measurement data on the position of Network Users. Hence, there is a need for online-based measurement for offtakes and deliveries of hydrogen for all metering points.

This aids the TSO to compute a continuously updated Accumulated System Balance (ASB), based on online measurements obtained from all individual System Users. Energinet will calculate and publish the continuously updated ASB. This signal, together with the Accumulated Network User Balance (ANUB), enables the Network Users to conduct proactive balancing of their own portfolio.

The Hydrogen Network has more flexibility than the electricity system but is less resilient than the natural gas system. Ongoing Energinet analyses will shed more light on this during the maturation of the Hydrogen Network. However, the preliminary results indicate that the System Users can bring the Hydrogen Network out of its physical boundaries, potentially jeopardizing the system integrity and security of supply, if the balancing model's restrictions are not stricter than those applied in the natural gas system.

The pressure in the Hydrogen Network can be higher than the pressure purely required for transport capacity. Hence, energy can potentially be stored for a limited amount of time in the infrastructure, which is known as Linepack. The operational pressure range in the system is directly proportional with the available System Linepack Flexibility (SLF), which is the linepack that is available for balancing purposes, and hence the short-term storage opportunities.

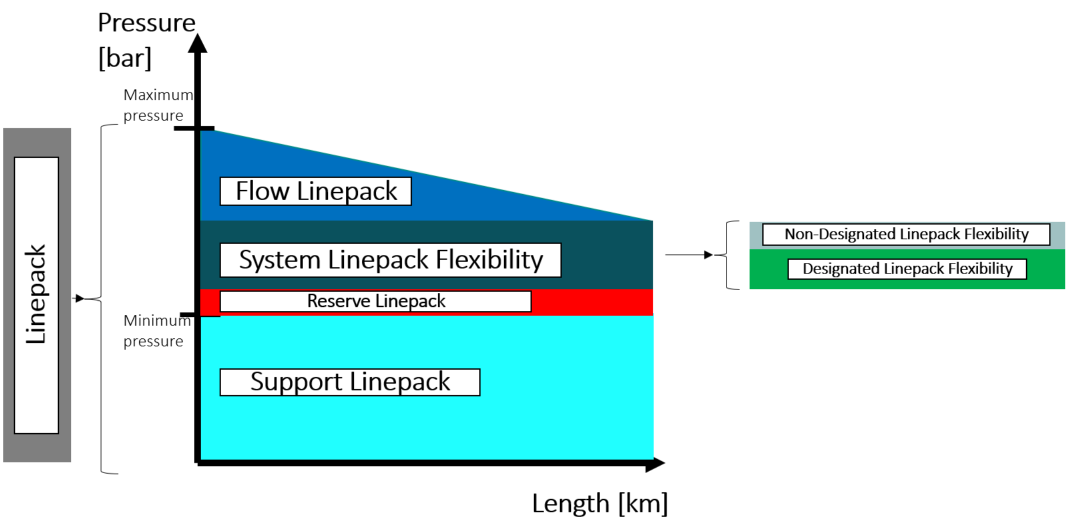

Figure 1: Dissemination of linepack into its four main subcomponents.

Linepack can be disseminated into four main subvariants, namely Flow Linepack, Support Linepack, System Linepack Flexibility and Reserve Linepack, as illustrated in Figure 1.

The flow linepack reflects the pressure range that drives the transportation of hydrogen. With no pressure difference, no hydrogen will flow.

The support linepack is the linepack needed to ensure minimum pressure. If the objective of the Hydrogen Network is to be purely transport of hydrogen at a fixed pressure point, the total linepack consists of the Flow Linepack and the Support Linepack. However, Energinet's vision is to design a Hydrogen Network that ultimately ensures large quantities of hydrogen transportation, while accommodating the demand for a flexible utilization of the Hydrogen Network.

Reserve linepack reflects a portion of the total linepack that is allocated for TSO balancing purposes and to ensure a certain Survival Time of the system. Reserve linepack is needed when the physical boundaries are close to be jeopardized due to i.e. imbalances that Network Users are unable to mitigate or the occurrence of disturbances.

The system linepack flexibility (SLF) leads to flexible utilization of the Hydrogen Network. Therefore, the SLF will be made available for the Network Users. Its size depends on the utilization of the system.

The SLF indicates the tolerance band of the Hydrogen Network for which it can be operated safely within. Thus, implementation of the SLF constitutes the fundament for creation of a balancing model, enabling the Network Users to operate their portfolio dynamically. The SLF can then be further divided into the summation of all Network Users' Designated Linepack Flexibility (DLF) added with the Non-designated Linepack Flexibility (Non-DLF). This will be further elaborated in chapter 4.

As previously described, the flow linepack ensures transportation of hydrogen. When the quantity of hydrogen transportation is large, the slope of the flow Linepack (in Figure 1) is increased, yielding a diminishing SLF, and vice versa for transportation of small hydrogen quantities. This is illustrated in Figure 2, where low system utilization yields a high amount of SLF.

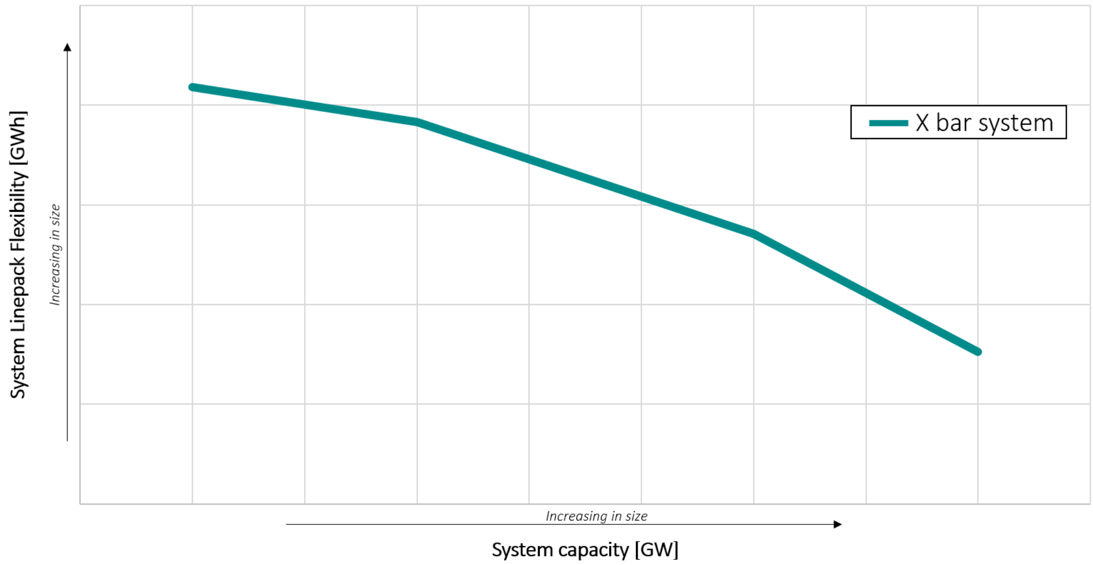

Figure 2: Correlation between utilized system capacity and available system linepack flexibility (SLF).

Thus, System Linepack Flexibility and reserve linepack are crucial for the design of a hydrogen balancing model, as elaborated on in chapter 4 on Balancing Model Composition.

4. Balancing Model Composition

For the Network Users to be able to maintain balance, they must know the limitations of their imbalance of hydrogen for their portfolio. This chapter will present how these limitations will be presented to the Network Users in a functioning balance model and how the interface of the balance model could look like. The System Linepack Flexibility (SLF) is distributed so that each Network User is allocated their own Designated Linepack Flexibility (DLF) while a collective Non-Designated Linepack Flexibility (Non-DLF) is provided for sharing among all Network Users.

The SLF will be calculated based on nominations for each Hydrogen Operation Day (further described in chapter 8). The nominations are the Network Users' expected use of the Hydrogen Network, enabling Energinet to calculate the SLF for the upcoming day. Therefore, the DLF will be allocated for the duration of the Hydrogen Operation Day. As the market develops it might be necessary to shorten the timespan for calculation of the SLF. It should also be noted that the size of the SLF depends on the utilization of the system. If all the capacity in the system is nominated for usage, there will be no flexibility available.

Accumulated System Balance

The Accumulated System Balance (ASB) is the aggregated balance for all Network Users and must stay within the SLF. The ASB is calculated and broadcasted to the market on high-resolution data, to enable dynamic operation for the Network Users. The SLF consists of all the DLF and Non-DLF. The non-DLF is the Linepack Flexibility that are commercially available in the system after the DLF has been allocated to the Network Users. It is calculated in the following way:

$$SLF = Sum(DLF) + nonDLF$$

The SLF, the ASB and the Reserve Linepack is shown in Figure 3. In example A the ASB is entering the Reserve Linepack. When this happens, the TSO is forced to take action to bring the system back into the SLF. This is called TSO balancing actions, covering the actions that the TSO can activate, when the ASB enters the Reserve Linepack. These are described further in chapter 6. However, the purpose of the model is to enable the Network Users to perform self-balancing through incentives that makes the Network Users react when the ASB is approaching the Reserve Linepack. This is elaborated on in chapter 5.

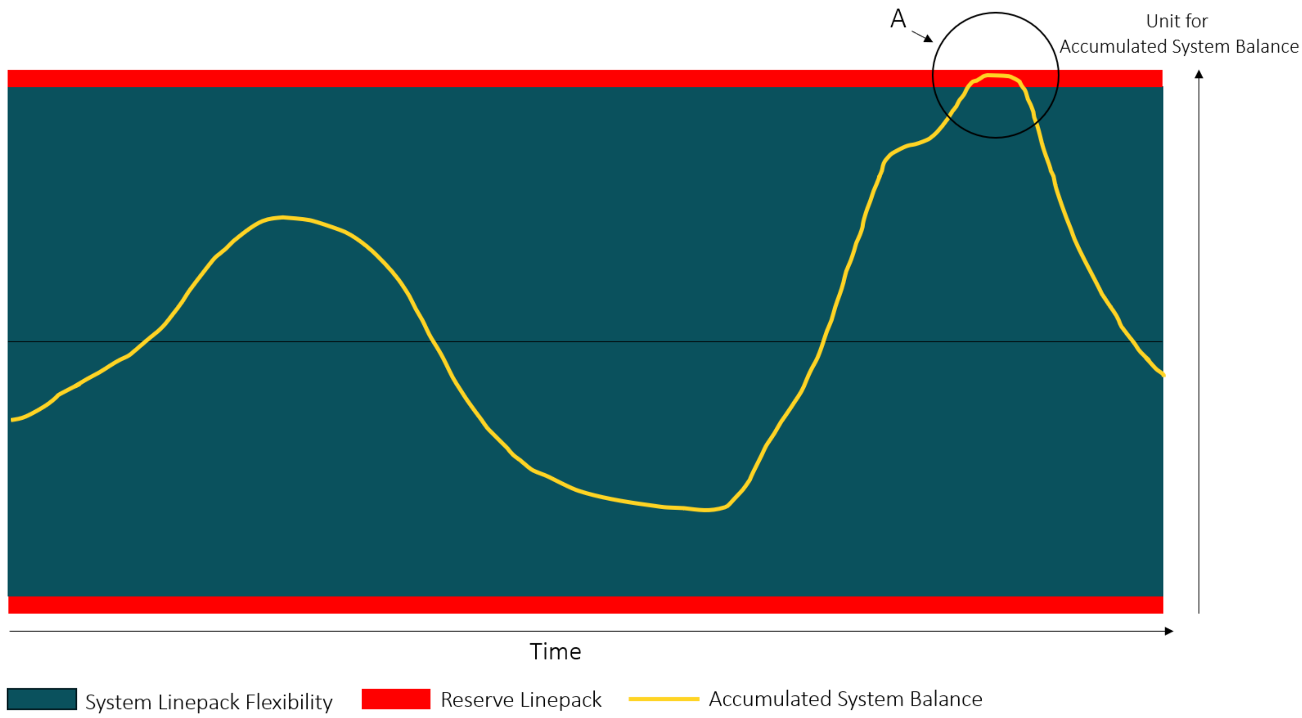

Figure 3: Illustration of the SLF, the Reserve Linepack and the ASB. In example A, the ASB exits the SLF, and the TSO will have to take action to bring the system back into the SLF. Further elaborated in chapter 6.

Designated Linepack Flexibility

When a Network User buys capacity in the Hydrogen Network, a pro-rata amount of the available SLF is being allocated along with the capacity, i.e. if a Network User has booked 10% capacity, 10% of the available SLF will be allocated as Designated Linepack Flexibility (DLF). In the early maturation phase of the Hydrogen Network, the flexibility will be allocated for the duration of the Hydrogen Operation Day. The allocated flexibility is called Designated Linepack Flexibility (DLF), and the Network User is allowed to act freely within its DLF. Hence, the Accumulated Network User Balance (ANUB) can vary within the DLF without consequences. This is illustrated in Figure 4.

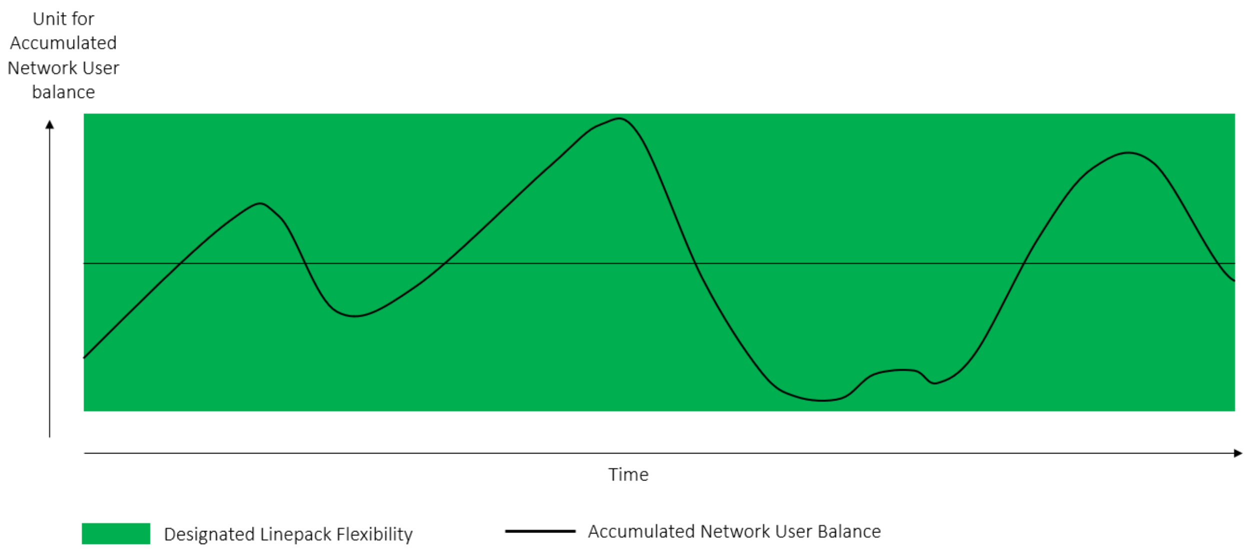

Figure 4: Illustration of a Network User's DLF and ANUB. In this example the Network User stays within its DLF and therefore no balancing actions from the TSO is necessary.

In Figure 4 the Network User is utilizing its DLF which allows the sum of injected hydrogen to deviate from the sum of extracted hydrogen over time. Furthermore, the Network Users can trade DLF with each other, which is elaborated on in chapter 5.

Non-Designated Linepack Flexibility

The non-DLF is Linepack Flexibility that is not allocated to any Network User. The non-DLF is used by Networks Users when they exit their DLF. The non-DLF is common flexibility and all Network Users, who have exited their own DLF, are using it collectively.

The possible interface for the Network Users

In general, the Network Users are allowed to exit their DLF and use the non-DLF, as long as the ASB is within the boundaries of the SLF. If the ASB exits the SLF, only Network Users who are contributing to the ASB exiting the SLF and are outside of their DLF are affected by the TSO balancing actions (see chapter 6). These Network Users, who are outside their DLF in the same direction as the ASB exits the SLF, are defined as Causers.

For the Network Users to perform proactive balancing and react on the position of the ASB, the Network Users will have access to an interface which shows all the relevant components of the balancing model. This is to make it possible for the Network Users to act accordingly to the ASB, if they exit their DLF. The intention is to create an interface as shown in the preliminary example in Figure 5 below.

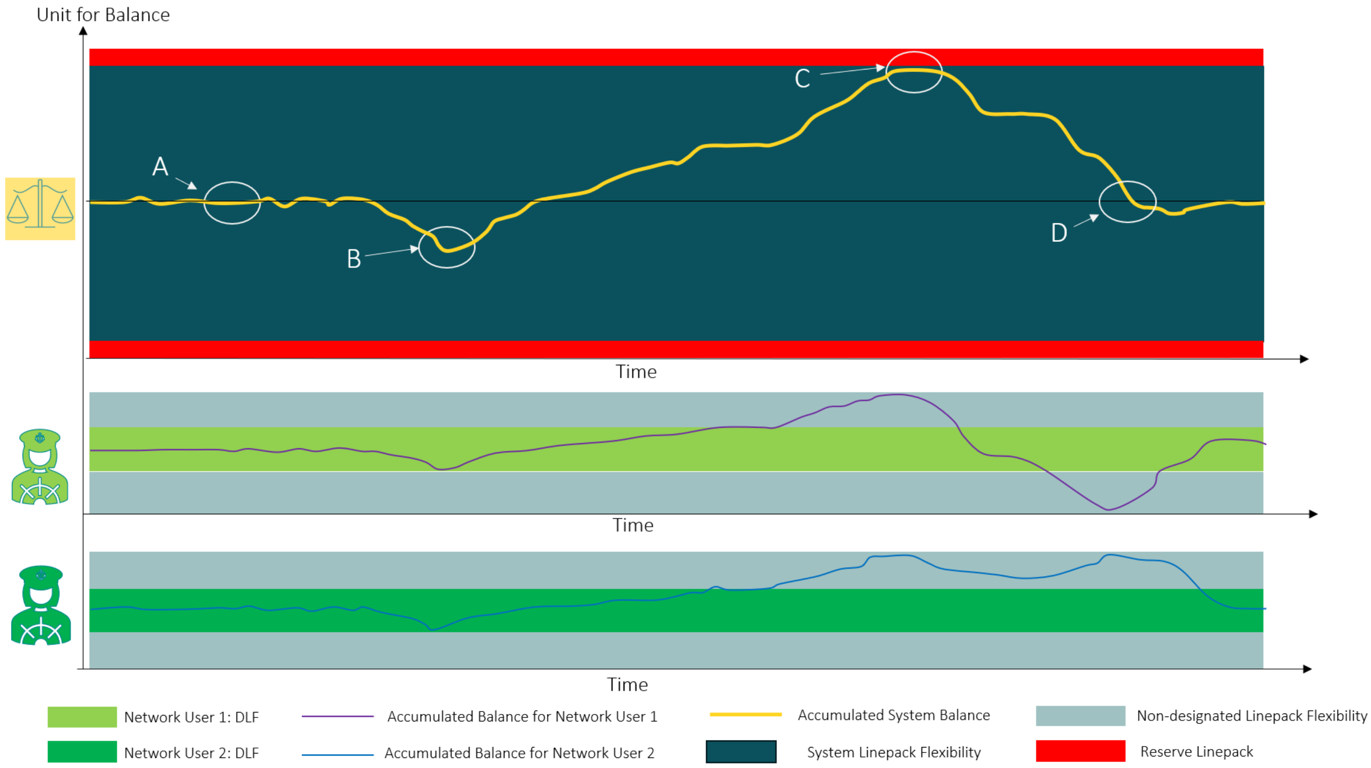

Figure 5: Visualization of two Network Users' DLF (the two lower subplots) and the SLF (upper subplot). The total available non-DLF is for the sake of the illustration positioned to surround each network user's DLF.

Figure 5 reflects the progress of the ASB when the network comprises of two Network Users. The figure is highlighted with four markers to demonstrate functions in the model:

- Mark A) indicates that the ASB is in the centre of the SLF, because both Network Users are positioned within the centre of their respective DLFs.
- Mark B) showcases an instance where both Network Users have approached the lower part of their respective DLFs. However, since the amount of non-DLF is abundant in this example, the ASB is only decreased partially from its centre value.
- From mark B) to mark C), both Network Users increase their individual ANUB, yielding a significant increase in the ASB.
- In mark C), both Network Users have exited their respectively DLFs, inducing the ASB reaching the limit of the SLF. Even though the Network User are allowed to position themselves outside of the DLF, the Network User must be aware of the position of the ASB.
- In transition from mark C) to mark D), the ANUB of Network User 1 has decreased sufficiently enough to force the ASB towards the centre of the SLF.

The balancing model is proposed as described above to allocate as much flexibility as possible to the Network Users but also accommodate the need of Network Users who does not need a lot of flexibility. With this model, Network Users, whose portfolio is stable over time, can stay within their DLF risk-free, and even sell the amount of flexibility they will not need. On the other hand, Network Users whose portfolio will vary a lot over time will be able to utilize the full flexibility of the system, if they accept the risk of the ASB exceeding its limits and the related consequences of the TSO balancing actions. The aim of the model is to find the balance between utilizing the flexibility of the system, and still being able to operate the system in a secure way.

5. Network User Balancing Mechanisms

This chapter outlines the Network User's balancing mechanisms which is the Network User's repertoire of mechanisms to control its balancing activities. The Network User is responsible for balancing its portfolios in order to minimize the need for the Hydrogen Network Operator to undertake balancing actions.

Hence, Energinet desires to facilitate mechanisms that the Network Users can use to fulfil their balance responsibility. The below sections describe the different mechanisms that the Network Users can deploy.

Utilize Designated Linepack Flexibility

Network Users can avoid any TSO intervention if they stay within the boundaries of their own Designated Linepack Flexibility (DLF). Thus, this is a risk-free flexibility that the Network Users are assigned for the duration of the Hydrogen Operation Day when purchasing entry/exit transport capacity.

Hydrogen trade between Network Users

The main principles of the hydrogen balance model are that the balancing rules must be market-based, and that Network Users must have the incentive to balance their own portfolio. Therefore, access to a trading platform and/or a Hydrogen Transfer Facility is needed for Network Users to have the possibility to balance their portfolio. A physical or virtual point at which Network Users can trade hydrogen with each other either bilaterally, and/or via a platform will be made available by Energinet or by a 3rd party provider.

The possible trading products are not yet decided, but a range of products are expected. The TSO can also trade in this market for balancing purposes. An example of a hydrogen trade is visualized in Figure 7, showcasing the change in the Network Users' Accumulated Network User Balances (ANUB's). The Network Users must be aware that a lead time from the trade to the hydrogen delivery is expected.

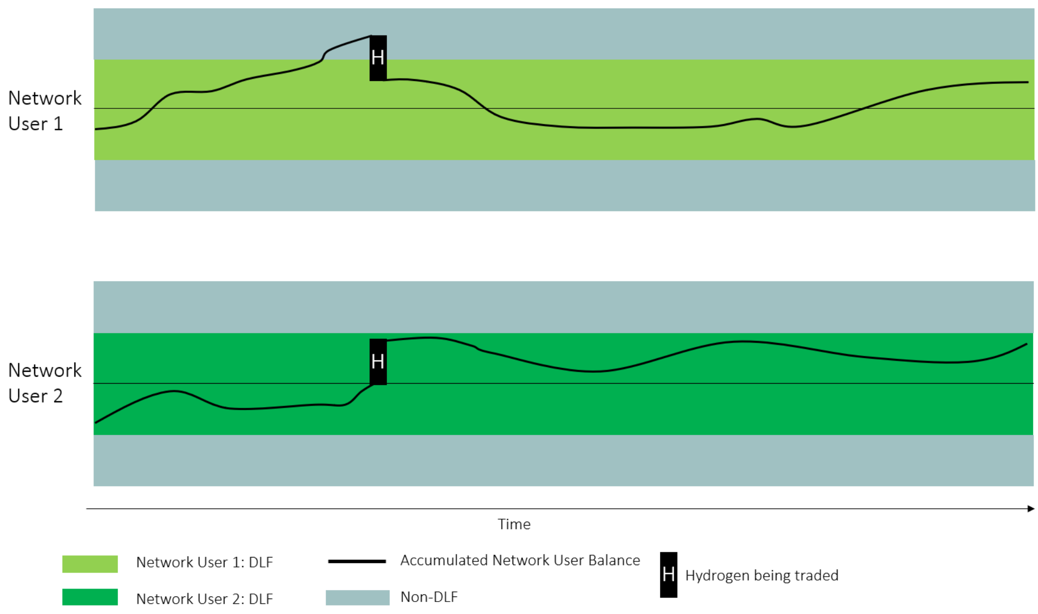

Figure 6: Network User 1 sells hydrogen to Network User 2, equal to the vertical changes in the Network Users' ANUB's.

DLF trade between Network Users

The Network Users will be able to trade their DLF with each other. This is relevant when a Network User wants to either increase its DLF, i.e. to reduce the risk of exiting the DLF while the ASB has exited the SLF, or decrease its DLF, simply because the Network User does not need its DLF.

An example of a DLF trade is illustrated in Figure 8 and Figure 9, where Network User 1 has sold an amount of its DLF to Network User 2 for an unspecified amount of time. In Figure 8, the arrows illustrate that Network User 1's DLF has become narrower for a time and then wider again, and in Figure 9 the arrows illustrate that Network User 2's DLF had become wider for a time and then narrower again.

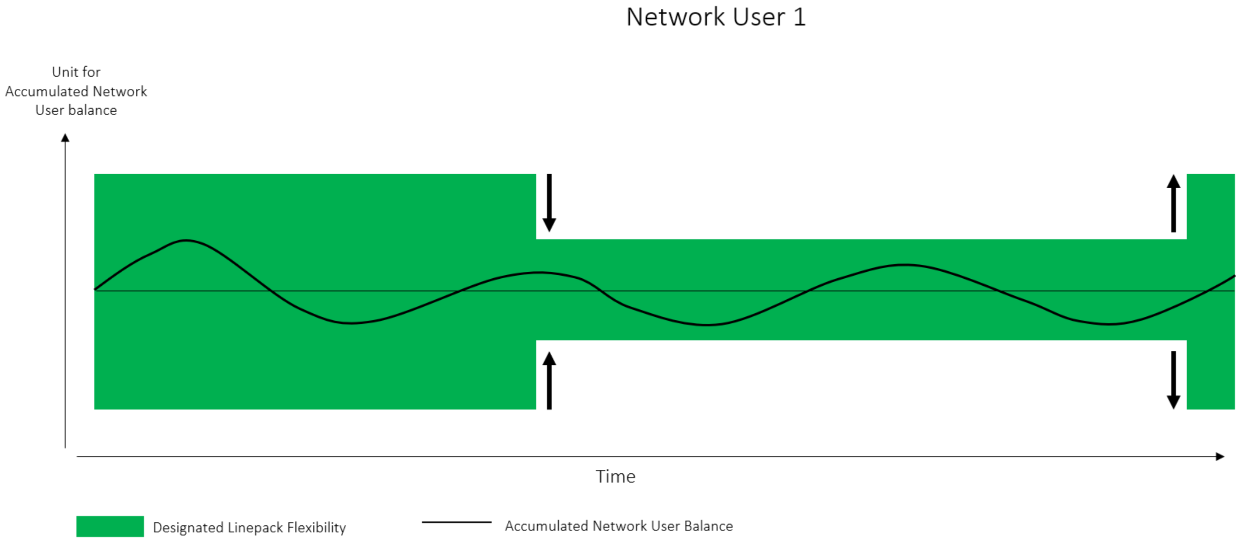

Figure 7: Network User 1 has sold some of its DLF and therefore its DLF has gotten narrower for a time.

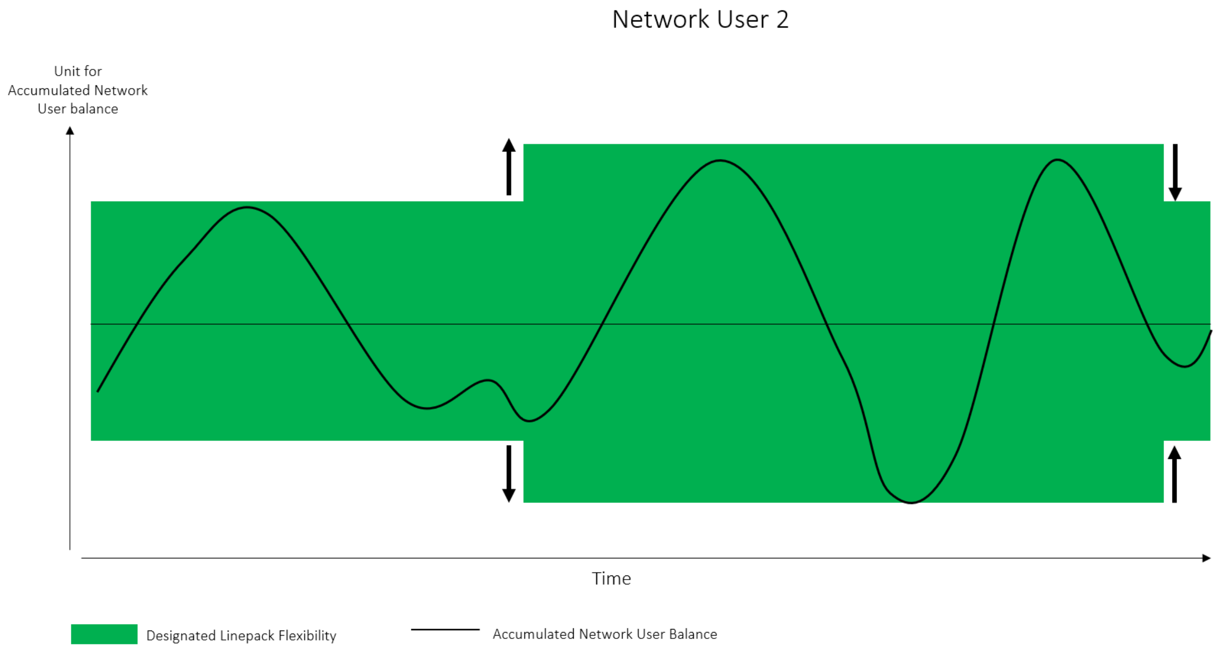

Figure 8: Network User 2 has bought some DLF from Network User 1 and therefore its DLF has gotten wider for a time.

Buy and utilize injection/withdrawal capacity at hydrogen storage

With time, the upcoming hydrogen infrastructure is expected to be connected to a hydrogen storage. This will provide the Network Users the ability to inject/withdraw hydrogen into/from the storage. Thereby, the Network Users get an extra tool to perform portfolio balancing activities.

6. TSO Balancing Actions

In cases where the Network Users fail to maintain the Accumulated System Balance (ASB) within the System Linepack Flexibility (SLF), Energinet will have to act. These actions are referred to as TSO balancing actions. If the ASB enters the Reserve Linepack it results in an activation of TSO balancing actions as shown in Figure 10, example A. This chapter will describe the functionalities of the balancing model within the Reserve Linepack. As mentioned earlier, only Causers (Network Users who are contributing to the ASB exiting the SLF and are outside of their DLF) is affected by the TSO balancing actions.

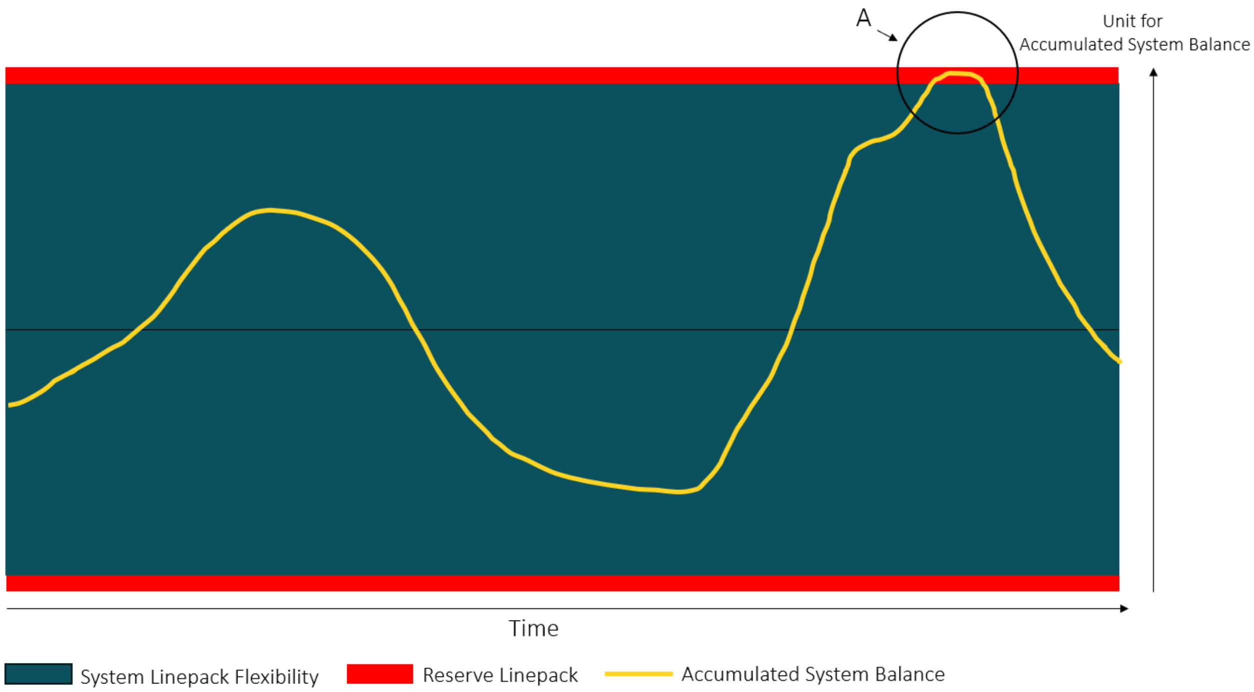

Figure 9: Example A showcase when the TSO balancing actions are deployed.

The TSO balancing actions that Energinet foresee to establish can be divided into:

- Commercial balancing actions
    1. Balancing service market
    2. TSO hydrogen trading
- Non-commercial balancing actions
    3. Prioritized cut-off of Network Users

The numbers above reflect the prioritized order in which the TSO balancing actions will be deployed in. Thus, Energinet prioritizes the use of the commercial balancing actions rather than the use of non-commercial balancing action. Already when the first System Users are using the hydrogen infrastructure, Energinet desires to provide access to a balancing platform where commercial balancing actions can be traded. However, the degree of utilization of this platform depends on the Network Users and the liquidity of the market. Energinet expects that in an immature market with few Network Users, mainly non-commercial balancing actions will be available.

Non-commercial balancing actions will be activated if commercial balancing actions are not available when needed. It can, especially in an immature market, become a challenge for the commercial balancing actions to sufficiently keep the system in balance. Energinet will in this case deploy cut-off of the Causers, and the size of the intervention depends on how much the boundary of the SLF is violated.

In the following the non-commercial and commercial actions are described in more detail.

Non-commercial balancing actions: Prioritized cut-off

In an immature market, cut-off of Causers is expected to be the only action available for TSO balancing actions. The action is a cut-off deployment of a prioritized list provided by the Network Users if the Network Users have multiple injection or extractions points within their portfolio. This action enables the TSO to cut-off specific hydrogen units from a specific Network User if the Network User causes the ASB to enter the Reserve Linepack.

An example could be a Network User whose hydrogen production is disrupted while the offtake remains constant. In this situation, the ANUB starts declining and at some point, the ANUB will exit the DLF and enter the non-DLF. The Network User becomes a Causer if the ASB exits the SLF. In this case the Network User's balancing mechanisms have failed to bring the ASB back into the SLF. Therefore, TSO balancing actions must be activated. In the case that the TSO commercial balancing actions fail or are not available to bring the ASB back into the SLF, the TSO is obliged to use non-commercial balancing actions. This means that the TSO disconnects injection or extraction points for the Causer(s). The details for this cut-off mechanism are not decided, e.g. how to handle an imbalance caused by a Network User's export flow, or to what extent the cut-off can be performed stepwise with incremental steps.

The size of the Reserve Linepack is not settled yet. However, the intention is to allocate as much flexibility as possible to the Network Users, without compromising the security of the network. Hence, the survival time will dictate the size of the Reserve Linepack.

Commercial balancing actions: Balancing service market

As the amount of Network Users increases, it is expected that the utilization of a balancing platform will increase. This platform enables the TSO to procure balancing services. It is the intention that the Network Users are providers of the balancing services. Balancing services are a function in the balance model, where Energinet pays Network Users to change their deliveries or offtakes to keep the ASB in the SLF. The cost for activating balancing services will be allocated to the causer(s).

The balancing service market can be designed with various functions depending on how the hydrogen market develops. An example could be that Energinet procures reserve balance capacity contracts for either up- or down regulations in their deliveries or offtake. Another example could be, that the TSO receives energy bids from Network Users, who desires to obtain an energy payment for activation of up- or down regulation. Nevertheless, the creation of a balancing service market will be founded on specific technical and market-related characteristics, allowing the TSO to procure balancing services. Energinet will communicate to the market when this is more matured.

Commercial balancing actions: TSO hydrogen trading

In a mature market, TSO balancing actions are expected to be carried out via a hydrogen trading hub (exchange with continuous trading). The TSO buys/sells hydrogen volumes by taking and placing bids/asks on an exchange platform. The volume traded will be allocated to the Causer(s) with a mark-up/-down on the price to ensure incentives to perform self-balancing and to cover the costs related to the TSO's balancing action. This platform is characterized by both Network Users and the TSO being allowed to trade.

Example scenarios for TSO balancing action deployment

Figure 11 showcases the deployment of each of the TSO balancing actions in different scenarios. The TSO hydrogen trading is not visualized here since its functionality is identical to the balancing service activation. It should be noted that the Reserve Linepack from previous figures is reflected in this figure with the yellow and orange zones summed.

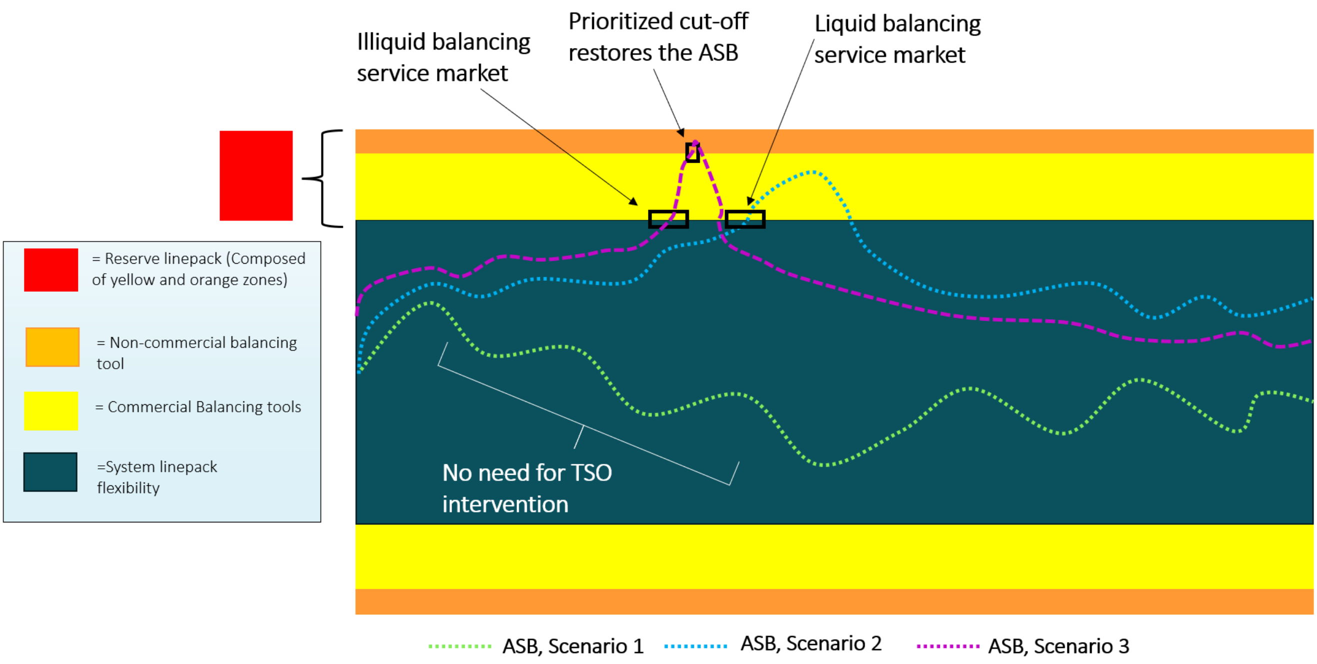

Figure 10: Visualization of the Accumulated System Balance (ASB) across different scenarios. NOTE: The yellow and orange zones summed in this figure correspond to the Reserve Linepack in previous figures.

- Scenario 1 (green): Since the ASB stays within the SLF, there is no need for TSO intervention.
- Scenario 2 (blue): At one point, the ASB exits the SLF and enters the yellow zone. The ASB must be restored and returned to the SLF, which is realized by activation of the balancing service market, which in this case ensures that the ASB returns to the SLF.
- Scenario 3 (purple): A change in the ASB occurs and it enters the system's yellow zone and thereby exits the SLF. For the sake of the example, there are no bids in the balancing service market. Hence, mitigation of the system imbalance is impossible within the yellow zone, yielding a continuous increase of the ASB. When the ASB enters the orange zone, the Causers experience a cut-off at some of their injection or extractions points. This has a rather immediate effect causing the ASB to return into the SLF.
  In an immature market where cut-off of Causers is expected to be the only available TSO balancing action, the yellow zone can be seen as an expansion of the SLF.

7. Imbalance settlement design

As described in the preceding chapters a certain amount of Linepack Flexibility is available to the Network Users when there is available capacity in the network. The imbalance settlement design in the hydrogen market refers to the cost for the TSO to bring the Accumulated System Balance (ASB) back into the System Linepack Flexibility (SLF) when it enters the Reserve Linepack (Figure 10). This cost will be allocated to the Causer(s).

As long as the market is immature, there will be no imbalance settlements, as Energinet will use prioritized cut-off in cases where the ASB enters the Reserve Linepack, as described in chapter 6. Consequently, the Causer will be directly penalized. Therefore, there will be no balancing costs passed on to those who create these imbalances.
This will only be the case until the market reaches a sufficient level of matureness, enabling the use of commercial balancing actions.

Managing imbalances that brings the ASB into the SLF is crucial to maintain stability and reliability to the Hydrogen Network. Energinet intends to create an imbalance pricing design to ensure that the Causers are the ones who will pay Energinet for bringing the ASB back into the SLF. This follows the '*polluter pays principle*', as known from both gas and electricity markets today. By designing the imbalance pricing design in this way, it ensures a cost-effective way of managing imbalances so that it is not all users of the Hydrogen Network who must pay for imbalance management through tariffs.

It is important to add that Network Users will only pay the imbalance price if they deviate from their Designated Linepack Flexibility (DLF) in the same direction as the ASB, and when the ASB exits the SLF. In this situation, the system imbalance must be managed, and the related cost will be allocated to the Causers. On 15-minute basis, the energy difference (imbalance) between the Network User's DLF and the Network User's ANUB will be calculated. The logic behind a 15 minute-based calculation of the Network Users' induced imbalances, is to align it with the resolution at which nominations and renominations are effectuated. This is explained in chapter 8

8. Hydrogen Operation Day

In years to come, the share of renewable energy in the electricity system will continue to rise, consequently increasing the fluctuations in the electricity production. This will challenge both the capabilities of the electricity grid and the balancing of the system. Therefore, a holistic approach to the energy markets becomes crucial. By integrating the future Danish hydrogen market with the existing electricity markets, synergies can be achieved.

The hydrogen market allows for a dynamic adjustment of hydrogen production and consumption, supplementing the fluctuations in the electricity market. In periods where electricity production exceeds electricity consumption, the excess energy can be used to produce hydrogen. Furthermore, flexible hydrogen producers and consumers are considered to be key providers of ancillary services in the future challenged electricity system. Finally, the interlink between the markets allows for the Network Users to mitigate the imbalances where it is most economical optimal at the given time.

The integration of hydrogen and electricity markets create a bridge between renewable energy sources, energy storage, and sector integration.

Nominations

The Network Users are obliged to make nominations to get hydrogen transported in the Hydrogen Network. Nominations act as a source of information from the Network Users to Energinet, which is key when operating and balancing the Hydrogen Network. For each Hydrogen Operation Day, the available System Linepack Flexibility (SLF) is calculated based on the nominations.

When introducing nominations to the hydrogen market, it is vital to consider the interlink between hydrogen production and the electricity markets. For now, Energinet expects the nomination process to take place the day before the day of operation in the hydrogen market, more specifically after the Day-Ahead electricity market gate closure time. The Day-Ahead results are considered important for many Network Users since the electricity prices are expected to have a direct impact on the producers' willingness to produce hydrogen. This way, the electricity prices, and each Network User's allocated capacity in the system will be known, enabling the Network Users to provide more accurate nominations.

Renominations

The Network Users must be able to revise the nominations after the submission deadline has passed. The revised nominations are referred to as renominations. The renominations provide flexibility for the Network Users, allowing them to optimize their portfolio in case of changes in demand, prices etc. Energinet expects the renominations to take place as close to the time of operation as possible without compromising on a safe and secure system operation. This enables the Network Users to utilize not only the Day-Ahead electricity market but also the Intraday electricity market and adjust their nominations accordantly. Finally, the renominations act as an important tool for the Network Users, allowing them to balance their own portfolio and hereby remain within their Designated Linepack Flexibility (DLF) or non-DLF respectively.

To promote the synergies between the electricity markets and the hydrogen market, the time unit of nominations and renominations are expected to always follow the prevailing Market Time Unit (MTU) in the Danish electricity markets. Today, the MTU is one hour, but will be 15 minutes at the time of commissioning of the Hydrogen Network.

Link between nominations and the electricity markets

The hydrogen market model will be designed as an entry/exit system. The Network User is obliged to nominate the anticipated hydrogen flow on all affected entry and exit points relevant for the Network User. Entry points refer to wherever hydrogen is injected into the system, including points related to hydrogen production, import or storage withdrawal. Exit points refer to wherever hydrogen is removed from the system, including points related to hydrogen consumption, export, and storage injection.

The Accumulated System Balance (ASB) and the Accumulated Network User Balance (ANUB) are based on allocations. In points with hydrogen production and consumption, metering of the actual flow is used for allocation. In export and storage points, the allocation is set to equal the matched nominations. Any virtual trading points for commodity exchanges between Network Users will also be allocated according to matched nominations.

Figure 12 illustrates the interlink between the nomination process and the timing of the electricity markets. The required lead time and the detailed process of nominations and renominations are still being investigated and will be concluded on at a later stage.

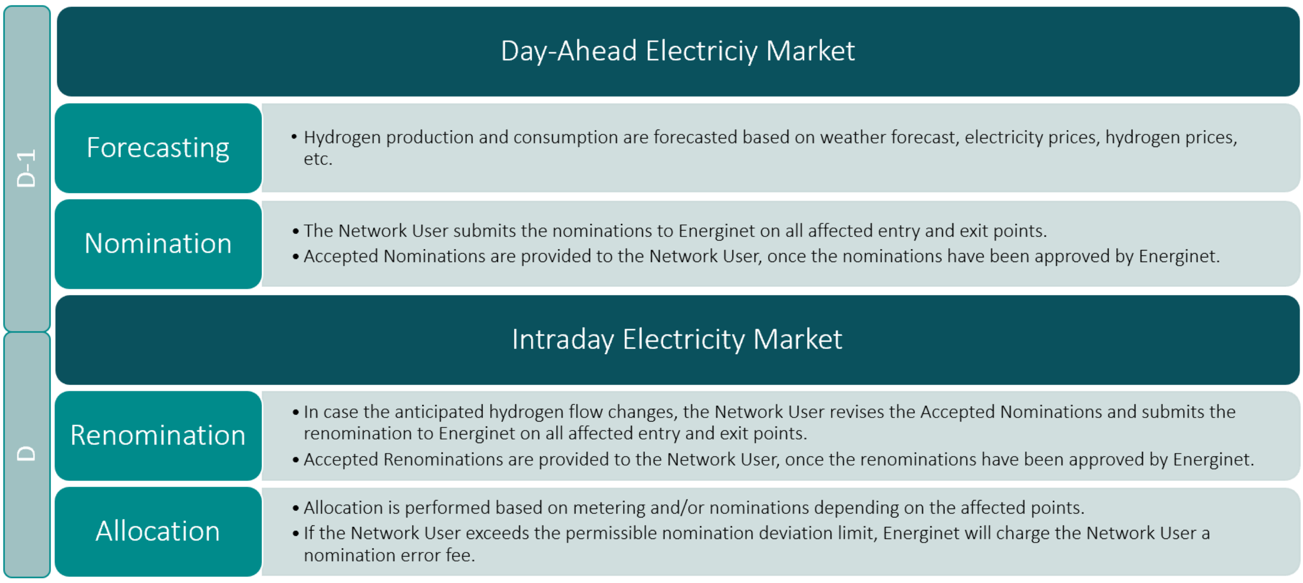

Figure 11: The timing of nominations and renominations, highlighting the dependencies between the hydrogen market and the electricity markets.

Nomination error fee

By receiving accurate nominations and renominations, Energinet can optimize the operation of the Hydrogen Network. A high nomination accuracy reduces the risk of unforeseen hydrogen flows and imbalances in the system. As a result, Energinet's confidence in operating the system increases, consequently reducing the amount of Reserve Linepack needed to ensure system security (Figure 1). Hence, Energinet can maximize the amount of linepack flexibility available to the Network Users, since the SLF is calculated based on the nominations. On a contrary, inaccurate nominations would force Energinet to use a more conservative operation philosophy.

It is the Network Users' responsibility to submit accurate nominations. Several parameters affect the Network Users' possibility to ensure this accuracy, wherefor Energinet expects to allow a margin of permissible deviation between the nominations and the actual flow on points related to hydrogen production and consumption. If the Network User exceeds the permissible deviation limit, Energinet will charge the Network User a nomination error fee. The size of the fee and the related terms and conditions will be determined at a later stage.

9. Definitions

Accumulated Network User Balance (ANUB): *The individual network user's accumulated balance position in the Balancing Zone.*

Accumulated System Balance (ASB): *The accumulated system balance of all Network Users.*

Balancing Model: *The rules and agreements that apply to balancing the Danish Hydrogen Transmission Network.*

Balancing Zone: *An entry-exit system, which may consist of more than one system, to which a specific balancing model is applicable.*

Capacity: *The given amount of hydrogen which can be flowed through the system under specific pressure conditions, stated in GW.*

Designated Linepack Flexibility (DLF): *The amount of Linepack Flexibility allocated to the individual Network User.*

Linepack: *The total amount of hydrogen that can be stored in the system.*

Network User Balancing Mechanisms: The repertoire of mechanisms that the network user can utilize to control its balancing activities.

Non-Designated Linepack Flexibility (non-DLF): *The non-DLF is flexibility that is not allocated to any Network User.*

Reserve Linepack: *When the ASB exits the SLF, it enters the Reserve Linepack, and the TSO Balancing Actions will be deployed in order to bring the ASB back into the SLF.*

Survival Time: *It is the amount of time it takes from an N-1 incident occurs to unacceptable pressure limits have occurred.*

System Linepack Flexibility (SLF): *The total amount of Linepack Flexibility that can be used by the Network Users collectively. SLF is equal to the sum of DLF and non-DLF.*

TSO balancing actions: *The actions undertaken by the TSO to ensure that the system stays within its accepted operational limits.*