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Bericht 3.4.1, 3.4.2: Cross-border interconnection possibilities in the distribution level (low- voltage grid)

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1. Background and Research gap

1.1. Cross-border Cooperation on Electricity in Europe (CBC)

1.1.1. Motivations for cross-border cooperation in Europe

Electricity supply cooperation has a long tradition in Europe. The European Union (EU) has extensive experience in developing an increasingly linked European electrical system, both in terms of infrastructure and market dynamics. The table below provides a brief overview of the history of cross-border interconnection in Europe.

Year	Description
Following World War II	CBC on Electricity has been pursued in a methodical manner
1921	The first cross-border interconnection was established
1951	The Union for the Coordination of Electricity Production and Transmission (UCPTE) was formed
1955	Up to a capacity of around 100 MW, cross-border power exchange was conceivable, and electricity delivery was mostly a national task
1960	The uniform 380 kV grid extended across Western and Central Europe which provided an important instrument for effective mutual aid in the case of power system failures, and for seasonal trading between coal-fired versus hydro plant-dominated regions
1970	Oil crises forced energy utilities to adapt their strategies to the new situation on the primary energy market
1980	Advance in telecommunication enabled cross-border electricity exchange
2009	UCPTE together with other organizations merged into the European Network of Transmission System Operators for Electricity (ENTSO-E)

The first European cross-border interconnection became operational in 1921 for the transmission of electricity from France via Switzerland to Italy, representing a distance of roughly 700 km. Cross-border cooperation on electricity has been pursued systematically in Europe since soon after World War II. In 1955, cross-border electricity exchange was possible up to a capacity of about 100 MW and electricity supply was mainly a national task. In the 1960s, the uniform 380 kV grid extended across Western and Central Europe and provided an important instrument for effective mutual aid in the case of power system failures, and for seasonal trading between coal-fired versus hydro plant-dominated regions. Energy utilities were compelled to alter their strategy in response to the new scenario on the primary energy market as a result of the oil crisis in the 1970s and as a result of advancements in telecommunication in the 1980s, cross-border electricity exchange enabled.

In 1951, the Union for the Coordination of Production and Transmission of Electricity (UCPTE) was established by representatives of eight countries in Western Europe. In the beginning, the aim of the organization was to contribute to economic growth through enabling an effective energy use by enabling the interconnection of electricity grids. Over the next decades, the UCPTE—through its joint elaboration of standards and procedures and the coordination of grid planning—significantly facilitated cross-border electricity trade and paved the way for the common EU electricity market as pursued by today's EU institutions and its Member States. Under the EU's Third Energy Package the UCPTE together with other organizations merged into the European Network of Transmission System Operators for Electricity (ENTSO-E) in 2009.

1.1.2. What advantages has the interconnected electricity system provided during cross-border cooperation in Europe?

The main benefits for the interconnected energy system that have been experienced throughout the previous 70 years of European cross-border electricity cooperation are:

A. **Competition benefits**
B. **Trading benefits**
C. **RES integration benefits**
D. **Reliability benefits**

We'll go through each one in depth in the following subsection.

A. **Competition benefits:** Electricity system interconnection generates a larger and more liquid market, allowing for new business cases that would not have been conceivable in a smaller market and increasing competition among generation companies. Meanwhile, final customers will benefit since, in sufficiently broad and diverse electrical markets, functioning competition results in lower supply costs for final customers.

B. **Trading benefits:** The interconnection of electricity systems extends the access to power plants that can be used to cover the domestic demand of electricity beyond the national fleet. This raises the question of when trading benefits can be accomplished? If the cost of importing power is less than the cost of operating domestic generation facilities, trading benefits can be realized.

C. **RES integration benefits:** Renewable energy generation is dependent on the availability of natural resources such as wind and solar radiation, and varies by country and location. Excess power generated by renewables in one part of an interconnected system does not need to be curtailed at zero value and can be exported to other sections of the system where its value is higher at the same time, for example due to a lack of domestic resources or differing demand patterns. Cross-border cooperation on electricity improves a country's ability to integrate renewable energy sources and allows countries that rely on fossil fuel imports to reduce their reliance.

D. **Reliability benefits:** To effort to protect against shortfalls in generation capacity, which lead to non-coverage of electricity demand, countries in Europe formerly organized reserve capacities at the national level.

But what factors cause the shortfall in generation capacity?

There are two probable possibilities:

- ✓ The rare case of an unplanned and simultaneous outage of several power plants
- ✓ Lack of renewable or fossil resource availability

Interconnection of electricity systems provides for a common reserve on a system wide level, minimizing the required capacity volume and total societal expenses, to ensure supply security. Moreover, because national transmission system operators (TSOs) can share balancing reserves and devices for power flow control across borders (e.g., FACTS or HVDC links), an interconnected electricity system provides reliability benefits for everyday instantaneous supply and demand balancing, reducing overall societal costs.

1.2. Developing cross-border interconnectors

Cross-border interconnectors are an absolute requirement for cross-border power trade. A combination of political, technical, and economic factors can determine whether and how cross border interconnector are produced.
Interconnectors built across borders must meet a number of basic requirements, including:

- ✓ satisfying some sort of economic test
- ✓ Considering the rules and regulations
- ✓ Obtaining support from stakeholders

In addition, there is the complicating element of cross-border co-ordination across policy makers, regulatory institutions and utilities which may face differing sets of interests, policies and regulations according to their own jurisdiction.

1.3. New actor named Citizen Energy Communities (CEC)

The European Union's (EU) energy policy prioritizes increasing the share of renewable energy sources (RES). The EU Directive on the promotion of RES prescribes that at least 32% of the gross final energy consumption in the EU should be generated on the basis of RES until 2030 (art. 3(1) Directive 2018/2001/EU). Most likely, this share will even be increased to 38–40% as suggested by the EU Commission in July 2021 in the context of the European Green Deal [1]. The achievement of this goal is fraught with difficulties.

- One of them being the integration of distributed electricity generation [2], i.e., production from RES which is connected to the distribution grid, in the electricity system [3,4].
- Operational constraints faced by distribution system operators (DSOs) are:

1. Congestion which urgently need to upgrade their networks and the operation by reinforcing grid infrastructure
2. Implementing flexibility technologies, for example storage and demand response [5–7].

- Growing electrification of the heat and the mobility sector add to the complexity as electricity consumption is expected to rise causing more pressure on the available grid capacity [8].

A few articles study the EU legal option of linking distribution networks across national borders via locally organized energy communities and quantify the economic benefits in terms of system cost savings, based on the issues outlined above. While the topic of interconnecting electricity systems across borders has widely been investigated, existing research focuses almost exclusively on the transmission system level [9]. It is established that transmission grid expansion and market coupling in Europe have the potential to increase the overall welfare and generation adequacy [10] and that grid extensions are essential for a cost-efficient integration of a high share of RES [11,12]. Historically, cross-border electricity interconnections were only used as additional backup capacities for national electricity markets [13]. Cross-border transmission connections, therefore, only exist on a high voltage level (110 or 380 kV) and are operated by the transmission system operators (TSOs). Article 16 of the recently adopted new European Electricity Market Directive (EU 2019/944) opens the possibility of cross border “citizens energy communities” (CEC) [14] in other words CEC which is known as a new actor provides the option for civic cooperation in the field of transmission energy at distribution systems. As a result of the new regulation, new concepts for a medium and low voltage cross border energy exchange could arise. This results in the need to analyze the benefits such cross-border electricity exchange concepts can deliver on a distribution grid level. Linking distribution systems across borders may also facilitate cooperation between EU Member States (MS) for the energy transition on a local level, especially in border regions. Border regions are typically less developed in economic and infrastructural terms. Partly, this stems from natural borders, i.e., rivers, lakes, or mountains, but to a larger extent this is a result of historical, political and administrative divisions causing mutual distrust between countries and subsequent unwillingness to cooperate [15].

1.3.1. What is Relationship between CEC and DSO?

As one of the potential tasks of CEC could be distribution system operation, Directive 2019/944/EU provides several options for organizing the relation with the DSO. As a minimum requirement MS are obliged to ensure that DSOs “cooperate with CECs” and facilitate the transfer of electricity “within CECs” for a “fair compensation” from the CEC. In addition to this option of “cooperation between DSOs and CECs” MS have the option to allow “CECs to autonomously manage distribution networks”. In this case, the proximity condition of members of the CEC has to be fulfilled, as they would then have the right to manage distribution systems in “their areas of operation”. This is also further illustrated by the conditions if such a right is granted to CECs which mainly refer to the regulation of connection points with neighboring networks (art. 16(4 a-b)). Under this option, MS may also decide to grant specific exemptions to CECs including the rules on the procurement of energy to cover losses and non-frequency ancillary services in its system, the requirement that tariffs, or their methodologies, are approved prior to their entry into force, the requirements to procure flexibility services and to develop the system on the basis of network development plans, and the requirements not to own, develop, manage or operate recharging points for electric vehicles and energy storage facilities. These exemptions would grant the operator of the CEC (either the DSO or the CEC acting as DSO) considerable leniency in the development, the operation, and the charging of network tariffs [18].

Overall, Directive 2019/944/EU leaves a large degree of discretion to the MS in determining the relation between CECs and DSOs. Some MS might exclude system operation from the potential task package of CECs and other might allow CECs to autonomously operate systems and possibly also grant them special exemptions in their national legal frameworks. The implementation is not only relevant for the role of CECs, but is just as important for DSOs. All DSOs will have to prepare to at least cooperate with CECs [18].

2. Research goal and questions

One of the purposes of linking distribution systems across border is facilitating cooperation between EU MS for the energy transition on a local level, especially in border regions. Another goal may be to have as much renewable energy produced, marketed, delivered, and consumed by actors within the two countries as possible. In General, the objective of this research is to examine the possibilities of cross border interconnection in the distribution level responding to the following research questions:

1. Would it be feasible the electricity distribution grids of two region are directly interconnected via a cable?
2. which possible challenges two electricity distribution grids in the direct interconnection may face?
3. whether formation of an islanded electricity without connections to the transmission grid on either side of the border within two distribution network is feasible? (Islanded here means that only one producer or consumer in one MS gets connected to a distribution grid in another MS)
4. How linking cross border interconnection in the distribution level can become a part of the solution to integrate distributed RES in the EU?
5. How linking cross border interconnection in the distribution level can become a part of the solution to flexibility technologies efficiently?
6. What are the economic benefits in terms of system cost savings of connecting distribution systems across national borders in the EU?
7. What are legal options of CEC to connect distribution systems across borders in the EU?

3. Research Hypotheses

In this part we can refer to the benefits of cross border power interconnection. So, with the myriad benefits of cross-border interconnection, the question of why cross border connections is so important can be answered. Cross-border power interconnections bring about a number of benefits for participating countries and beyond [1], among them:

- ✓ Enhance security of electricity supply (SoS) by providing support functions between interconnected electrical systems
- ✓ Ensure the stability and frequency of the two systems
- ✓ Exploit price differences through power imports and exports thus increasing economic efficiency
- ✓ Harness renewable energy sources by allowing the transmission of excess renewable generation
- ✓ Develop the Internal Energy Market in Europe
- ✓ Reduce the annual cost of the district electricity system

4. Methodology

In this context, we have reviewed some of existing adopted methodology among them article [18] provides the solutions based on linking two distribution systems by “Switchable element”. In particular, this article [18] proposes a novel solution to facilitate the linkage of distribution systems across borders, by implementing “switchable elements” which allow connecting distributed generation (e.g., a wind park or a solar field) or flexibility technologies (e.g., a flexible consumer or storage) to both of the two bordering MS without interconnecting the distribution systems at any point in time.

4.1. Technical Section: Cross-border connections on distribution system level

As previously said, this paper [18] provides a novel technique, namely the use of a "switchable element" to connect distribution systems. Figure 1 depicts the idea of using a "switchable element" to connect two distribution networks.

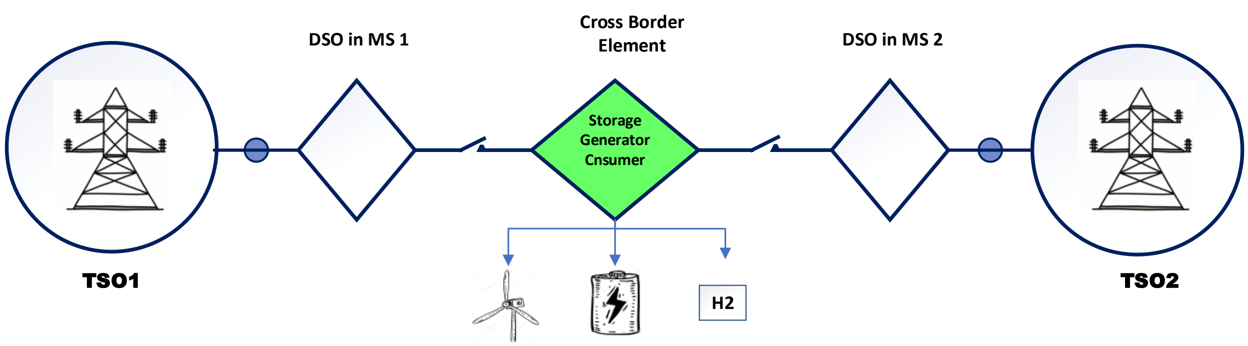

Fig1: Switchable cross-border element

This cross-border element can entail electricity loads of two cities, their respective renewable electricity generation plants, a battery storage and an electrolyser and it has switchable connections to two different distribution systems, i.e., one for the connection to the distribution system of the region in MS 1 and another for the connection to the distribution system of the region in MS 2. As a result, the switchable element is shared between the two zones, allowing both to benefit from the cross-border element's flexibility.

- **Place of switchable element**

It makes no difference where the switchable element is located, whether it is on the border or in one of the two MS, as long as it can be connected to the distribution systems in both MS.

This article [18] depicts a situation in which the switchable element can be linked to either the MS 1 or MS 2 area, but never both at the same time, due to current regulations and technical constraints. As both connections are never used at the same time, this implies that the distribution systems are never directly connected. The main idea is that the element can temporarily provide additional flexibility to the connected systems for specified time periods, i.e., in 15 min intervals when needed.

Implementing such a switchable element could facilitate CBC at the local level for the energy transition. Ideally, the switchable element would then offer additional flexibility, i.e., helping to resolve congestion or providing generation, and thus result in potential benefits for both regions.

4.2. Model and Input Parameters

The calculation of potential economic benefits of a cross-border CEC using a "switchable" link is discussed in the next section. To highlight the technical and economic impacts of a cross-border energy community, a mixed-integer programming model was developed. The model is created using the Python programming language, the Pyomo modeling package, and the CPLEX solver. It is powered by an eight-core processor with 64 GB of RAM.

4.2.1. Electricity System Cost

This article [18] focuses on system cost savings as a measure for creating economic benefits in order to examine the possibility of cross-border CEC for the aim of integrating RES and decreasing congestion at the distribution system level. An optimization model is proposed to assess the potential economic benefits of connecting distribution systems across borders via a switch element. The model's goal is to reduce the cross-border region's overall power system cost by properly utilizing the switch element. [19], [20] describe two different approaches for calculating electricity system costs. The [18] model employs a simplified way to assessing system costs based on existing grid fees and electricity curtailment costs. The grid fees reflect the costs of the transmission grid investment and utilization. They are directly related to the capital expenditures for grid extensions. The electricity system costs $C_{System}(r)$ for a region r are divided into two cost components:

$$C_{System}(r) = C_{Grid}(r) + C_{Cur}(r)$$

The grid costs $C_{Grid}(r)$ of a region r are determined by the maximum grid usage in one quarter of an hour over the whole year. They are calculated by multiplying the capacity grid usage price $C_{Capacity}(r)$ by the maximum grid demand/grid feed-in $P_{Max}(r)$. This gives:

$$C_{Grid}(r) = C_{Capacity}(r) * P_{Max}(r)$$

The current electricity capacity prices $C_{Capacity}(r)$, which is the TSO on both sides of the border, are used in the model.

In addition to the respective grid usage costs, the model objective function includes an additional revenue for the avoidance of curtailment on a TSO level. These costs are calculated as follows:

$$C_{Cur}(r) = c_{Cur}(r) * V_{Cur}(r) * r$$

The specific transmission network curtailment costs $c_{Cur}(r)$ are calculated from the total annual congestion expenditures of the respective TSO and the annual amount of electricity curtailed.

As a result, we have:

$$C_{System}(r) = C_{Capacity}(r) * P_{Max}(r) + c_{Cur}(r) * V_{Cur}(r) * r$$

The avoided curtailment volume $V_{Cur}(r)$ is equal to the local potential increase of renewable electricity self-consumption and, thus, to the reduced transmission grid feed-in volume. However, an increased self-consumption does not directly lead to an avoidance of curtailment by the TSO. Cost is avoided only if this self-consumption is at times when the TSO has to apply curtailment. Therefore, only a fraction r of the increased self-consumption is considered. Based on historical data, [18] estimates that 5 % of the total feed-in energy would have been curtailed on a national level and, thus, [18] chose $r = 0.05$. Congestions on the local electricity distribution grids or electricity transmission losses have not been considered. The presented system cost calculation methodology only considers the costs on the transmission grid level. Since the introduced switchable element connects two distribution grids, these costs are not part of the electricity system cost. These additional expenditures have to be covered locally.

4.2.2. Scenario

The idea to link distribution systems across national borders in the EU emerged in 2015 among stakeholders in a cross-border region between the Netherlands (municipality of Emmen) and Germany (municipality of Harn). While Emmen has a high electricity demand due to industrial consumers, Haren has occasional high surpluses of electricity produced on the basis of RES, in particular wind energy. Jointly, the municipalities initiated the "Smart Energy Region Emmen-Haren" project (SEREH). The initial idea for the SEREH project and an electric cross border connection on distribution grid level resulted from the complementary properties of both regions. The idea was to establish a local energy system functioning across the border on distribution grid level, which facilitates the efficient matching of supply and demand on a local scale.

- **An overview of the characteristics of the two cities (Haren and Emmen):**

Options	Description
Population	Emmen is located in the Netherlands, with around 110,00 inhabitants and Haren is located in Germany, with around 25,000 inhabitants.
Share of RES in 2015	Emmen just covered 7% while Haren RES covering 110 % of their demand in 2015.
Annual electricity generation	Despite the different annual electricity demands and load patterns, the annual electricity generation from RES is almost the same in both regions.
Annual electricity demand	It can be considered Emmen as Region 1 and Haren as Region 2. Note, that the annual electricity demand from region 1 is more than twice than that of region 2. This is mainly due to the higher number of inhabitants in region 1 and the considerably larger industrial sector.
Geographically	The area of region 1 is approximately 40% larger than that of region 2, so the annual demand per km^2 of region 1 is about 26% higher than that of region 2.
Local electricity production	Region 1 can thus be classified as “urban high load” and Region 2 as the “rural low load” region. In the “urban high load” region, the local electricity production from RES exceeds its annual demand by 19%, while in the “rural low load” region it is 141%.
Renewable energy resources generation	The RES generation in the “urban high load” region mainly comes from large-scale solar parks, while the “rural low load” region produces most of its electricity from wind.

Three different connection elements (wind turbines, electrolyser, and battery storage) are separately analyzed in terms of potential system cost savings. Depending on the type of switchable asset, the capacities of the respective flexibility options from both regions are part of the cross- border element and thus switchable.

Specifications of various connections elements:

- **Wind Turbines:** For the switching of wind turbines, we assume that 29.4 MW wind capacity from each of the regions is switchable and now part of the cross-border element. Thus, the total switchable RES generation capacity of the shared element is 58.8 MW.
- **Electrolyser:** If the switchable cross-border asset is an electrolyser, the total switchable capacity is assumed to be 20 MW, since each of the two regions has a 10 MW electrolyser.
- **Battery Storage:** In the case of a switchable battery, the battery size is fixed to 10 MWh, 5 MWh from each region.

4.2.3. Reference case

For reference, without a cross-border connection, the energy situation in Emmen and Haren is simulated. For load coverage, each of the two cities can only rely on its own renewable electricity generation and the national transmission grid. Local electricity surpluses have to be either fed into the respective transmission grid or curtailed locally if the flow exceeds the grid capacity given [18].

5. RESULT

In this section, the result of analyzed research work and studies which will answer relatively much of the research questions raised in the second part and also discuss the method's results, which are reported in the methodology section.

5.1. The ability to connect the two areas' power distribution networks through cable(Direct Line)

In order connect two distribution networks via a cable, direct current (DC) line may be a solution [22], which however would imply significant costs. In case of electricity transfers over long distances, using such DC links might be an economically viable option. (See e.g., the field of connecting offshore wind farms [23]). Fig 2 shows two distribution systems which interconnected directly by cable.

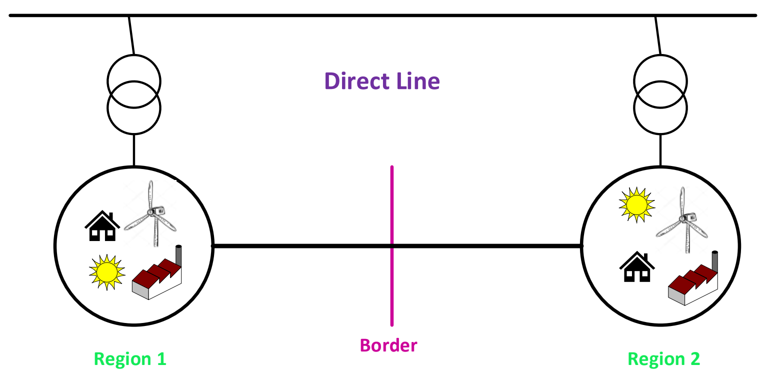

Fig2: Medium voltage cross-border Direct connection

Possible Challenges:

- While direct line seems to be most straightforward, it implies electricity flows between the two distribution systems which are hard to predict and control leading to operational challenges for the respective DSOs and TSOs.

- The purchase and procurement of balancing and control energy would be significantly affected, so that the DSOs and TSOs would have to closely cooperate and may even no longer be able to guarantee a stable and reliable grid operation.

In other words, it must be ensured for this type of connection that there will never be a free electricity flow between both countries to avoid uncontrollable and unpredictable electricity transfers between two transmission grids. This means that locally produced electricity can be transferred only to the neighboring region for self-consumption within that region, but a further transfer into the corresponding transmission grid must be avoided.

5.2. Ability of formation of an islanded electricity without connections to the transmission grid on either side of the border within two distribution networks

If two electricity distribution networks form an islanded electricity:

- The electricity distribution grids are directly connected to each other.
- There are no connections to the transmission grid on either side of the border.
- The electrical loads have to be fully covered by the local electricity generation.
- A further extension of renewable capacities is essential to enable such an electricity system.
- Such a setting is likely to be technically less problematic.
- The potential benefits for solving congestion problems in the system by such a connection are very limited and it does not contribute to solving the structural problem of congestion resulting from intensified use of the distribution system.
- This is currently already the case in some regions with special geographical properties such as valleys surrounded by high mountains.

Islanded Electricity

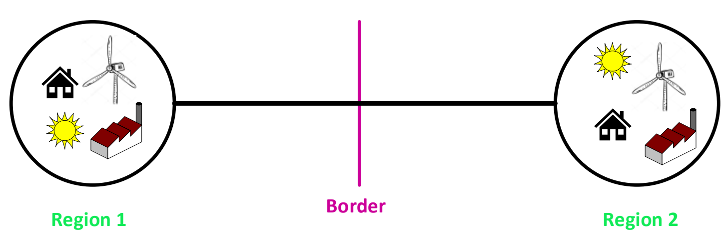

Fig3: Medium voltage cross-border islanded connection

5.3. Case Study Result

Based on the results of the model optimization (Mentioned in the Methodology part), electricity flows and electricity system cost savings are calculated and analyzed.

5.3.1. Electricity Energy Flows

The summary of the case study results in term of the **Electricity Energy Flows** is as follows:

- With a connection on a medium voltage level between Emmen and Haren, grid connection capacities to the TSO grid can be reduced, as the maximum grid feed-in of Emmen is reduced by 8.75 % and the grid connection of Haren is reduced by 38.48 %.
- The peak load does not change and is the same as in the Reference case without a connection.
- The maximum net capacity transferred on the German-Dutch cross-border connection is 54.6 MW. The annual transfer volume amounts to 65.3 GWh. The total volume is subdivided into 30.5 GWh export from the Netherlands to Germany and 34.8 GWh export from Germany to the Netherlands. This means that the German export of renewable electricity exceeds the import from the Netherlands by 12 %.
- Without a cross-border connection, Haren achieves a level of self-sufficiency of 89.84 % and Emmen a level of 78.75 %. By connecting both regions, the degree of self-sufficiency of Haren remains almost constant and the self-sufficiency of Emmen increases by 2.66 % to 81.41 %. It means that, the self-sufficiency rates of Emmen and Haren have not deteriorated with the cross-border connection.
- The local electricity self-consumption increases by about 2 % with a cross-border connection. This is also reflected in the increase of the self-sufficiency rates.
- Besides the increased renewable electricity self-consumption, the amount of electricity used for hydrogen production was increased by 14.84 %.
- By connecting the two cities, the curtailed electricity is reduced by 68 % to 2.8 GWh [24].

5.3.2. Total Electric System Costs

The summary of the case study results in term of the **Total Electric System Costs** is as follows:

In order to determine which elements (generation (renewable electricity generation plants), flexible consumption (electrolyzer), or battery storage) provide the highest economic benefit in terms of system cost savings for both regions, the elements are considered separately, i.e., either a wind turbine, or a flexible consumer, or a battery storage asset. Following section provides the results.

The result of the Generation element on system cost saving:

- Model results depict that the highest system benefit is achieved by switching electricity generation between the two regions. This leads to a reduction of both, **total transmission grid infrastructure** and **redispatch and curtailment costs**. Transmission grid infrastructure costs decrease by 3.96%, costs for redispatch and curtailment by 3.88%. Note that the cost savings for Haren's transmission grid connection are significantly larger than for Emmen. It means that, cost savings are, however, distributed unevenly between the two regions. While transmission grid infrastructure costs in the "rural low load" region decrease by approximately 12%, the costs of the "urban high load" region increase by about 2%. However, as the modeling objective function was to minimize the annual electricity system cost, this is explainable.

The result of the flexible consumer on the system cost saving:

- Connecting the two regions with a flexible consumer reduces total system costs. Transmission grid infrastructure costs in the "rural low load" region rise by 4.64 percent, whereas transmission grid infrastructure costs in the "urban high load" territory fall by 5.85 percent.

The result of the battery storage on the system cost saving:

- The lowest overall system cost reduction results from connecting the regions via a storage asset. Total system cost reduction of 1.70% compared to the reference case. Compared to the other two options (connection via generation and flexible consumer), system cost savings are distributed more evenly between the regions as both regions achieve reduced transmission grid infrastructure and reduced redispatch and curtailment costs. In the “urban high load” region, main cost savings result from reduced transmission grid infrastructure cost, while in the “rural low load” region reduction stem from savings in redispatch and curtailment cost.

Regardless how the two regions are linked, i.e., which switchable asset is deployed, linking leads to system cost savings. The different elements differ considerably in terms of the distribution of system cost savings (We mentioned above). In general, the model shows the benefits of a cross-border electricity connection on a distribution network with medium voltage level which electricity system cost caused by the region can be reduced by 34 % by connecting the two regions [24].

6. Discussion and Conclusion

For this report, we conducted a thorough literature review in order to determine and discuss the cross-border cooperation possibilities in the distribution network level. While the idea of interconnection energy networks across borders has received a lot of attention, much of the current research is focused on the transmission system level. Among all studied articles, [18] presented a novel method for linking two distribution systems across border with a "Switch" in terms of system cost saving. Since interconnecting distribution systems of Netherlands and Germany was the first case study in terms of across national borders in the EU, the mentioned method in [18] was implemented on the SEREH project. According to the various research, we assumed that CBC can provide benefits in the field of energy at the local level, i.e., the distribution system level, allowing cross-border regions to develop. According to the mentioned method in [18], we can present the result of this report as follows.

General assumptions about cross-border regions:

1. They are typically less developed in economic and infrastructural terms
2. They often may show complementary characteristics in terms of generation on the basis of RES and electricity load

The most important factor for system cost saving

According to [18], findings show that especially the complementarity of the two bordering regions of the considered case study is the source of benefits in terms of system cost savings. More specifically, all investigated options of the "switchable element" lead to a decrease of electricity system costs. However, the amount and the distribution of the calculated system cost savings, and thus potential benefits for a cross-border CEC, highly depends on the type of switchable asset connecting the bordering regions.

What is the solution for uneven distribution between two regions?

A "switchable generation installation" and a "switchable flexible consumer" both reduce total costs, but imply that the benefits are unevenly distributed between the two regions. While the "switchable production installation" provides benefits for the "rural low load region", the "switchable flexible consumer" provides benefits for the "urban high load region". Only the "switchable storage facility" would lead to benefits in terms of system cost savings for both regions, but also resulting in the lowest overall benefit. Achieving the highest overall cost savings thus does not correspond with the option where benefits are more evenly distributed. To resolve the problem of the uneven distribution between the regions, the additional system benefits need to be converted into remunerations for the CEC. The CEC could use the benefits for the advantage of the entire cross-border region in the interest of its members and shareholders, essentially contributing to CBC in the field of energy at the local level.

In other words, this uneven distribution of benefits could be mitigated by the organization via a cross-border CEC which distributes benefits to "its members or shareholders or the wider region where it operates", as it is requested by the provisions on CEC as established by Directive 2019/944/EU. In this way, the CEC is an organizational instrument to redistribute the benefits yielded by the switchable element in a more equal way, i.e., for the border community.

In what situations the optimal model is not applicable?

The optimization model developed within the existing research is limited to the economic perspective and thus is not applicable for:

- ✓ Technical implementation planning
- ✓ Type of power transmission between MS (AC/DC)
- ✓ Technical design of the switch circuit
- ✓ Dimensioning of cables
- ✓ Cable routes

What items are necessary from legal perspective to examine?

From a legal perspective, it would be necessary to investigate:

- ✓ The regulations on grid connections
- ✓ Potential support schemes
- ✓ Other costs which might be charged from system users in the respective countries

The overall findings of the model ([18]) calculation demonstrate that connecting distribution systems via a switchable element, whether it's an energy production plant, a flexible consumer (electolyzer), or battery storage, result in greater system usage and consequently system cost reductions.

Calculated system cost savings, on the other hand, cannot be used as alone indicator of the economic benefits of such a distribution system network. Instead, the findings show that coupling regions with complementary electricity generation and consumption characteristics (like in the case study, two MS regions, but this could also apply to two different distribution grids within one country) has the potential to increase (international) electricity transfer capacities in the EU electricity system while reducing the need for additional grid capacities in the transmission system.

Beyond cross-border regions, the findings show that using a switchable element to connect regions with complementary properties in terms of electricity generation and demand (e.g., urban-rural or industrial-residential) leads to better allocation of transmission grid capacities and, in general, more efficient system utilization.

However, the findings reveal that the distribution of benefits is highly dependent on the switchable element, and that the choice with the largest overall benefit may not be the same as the one with evenly distributed benefits.

This finding can help national legislatures incorporate CEC in their legal frameworks by providing the following guidance:

- ✓ CEC should be open to cross-border participation
- ✓ CECs should receive financial remuneration for contributing to system cost savings

Improved CBC at the local level for the energy transition would require consideration of these points while forming a national legal framework for CEC. Furthermore, cross-border CEC operation could help to reinforce border regions that are fundamentally weak.

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8. Abbreviations

CBC: Cross Border Cooperation

CEC: Citizens Energy Communities

DC: Direct Current

DSO: Distribution system operators

EU: European Union’s

ENTSO-E: European Network of Transmission System Operators for Electricity

FACTS: Flexible AC Transmission System

HVDC: High Voltage Direct Current

MS: Member States

SEREH: Smart Energy Region Emmen-Haren

SOS: Security of Electricity Supply

TSO: Transmission System Operators

UCPTE: Union for the Coordination of Production and Transmission of Electricity