Master thesis
Aalborg Universitet

04/06/2021

TRUE COST TARIFFS IN THE TRANSMISSION GRID FOR PTX AS A CONSUMER CATEGORY

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Foreword

This master thesis is done as a finishing project at Aalborg university, the department of planning under supervision of Professor Henrik Lund. The thesis has been made in collaboration with EA Energianalyse A/S where I have been working as a student assistant during execution of this project. It has been long and valuable schooling I have received in both the university and as a student assistant, and I am grateful for the opportunity.

Thank you, Henrik Lund, for guiding me though the process, and always bringing insightful knowledge, constructive feedback, and a good mood to our meetings. The same is true for Hans-Henrik Lindboe, a joke and a laugh is always on your lips. You have an answer for every question, an enormous insight in the field, and a network like no other. I am truly honored to be a student under both of you, and I could not have wished for better mentors. I am proud of being under your wings, you are both role models I one day aspire to be compared to.

A huge thank you to Freja Køllund for both moral support and constructive feedback. You are such a nice person, and a reflective planner. I am sure great things are coming your way my friend.

Thank you to Nina Stokkendal for sparing and quality control of calculations. And thank you to Morten Tony Hansen for sparing and looking out for me. You are both great colleagues that I hope the best for.

The greatest thanks are given to my 7-year-old son Liam. You are the apple of my eye, and I owe you everything. If it were not for you, I would never have been motivated to apply for university and aspire to make the best possible life for both of us. Thank you for always putting a smile on my face and believing that I am superman. It is very confirming that I can see you look up to me and that you tell me you do not want to go through life without me. I love you.

Anders Rosenkjær Andersen.

Abstract

This project investigates electrofuels as a decarbonization tool in the hard to abate sectors and how tariffs in the transmission grid affect the economy of an ammonia production facility. The need for a reforming of the tariff structure surrounding electrofuels is present due to the current structures failure to comply with both danish and EU regulation and the unfairness of PtX facility having to pay more than what they give rise to. The analysis in this project finds a suggested new tariff rate of 2,8 øre/kWh, that is found to better reflect what a PtX facility give rise to under the assumption that they are placed in a landing zone. LCOE calculations of the planned ammonia production facility in Esbjerg show that the ammonia price is highly sensitive to tariffs, and that the abatement cost can be reduced from 319 EUR/ton of CO_2 to 255 EUR/ton with the new suggested tariff rate that better reflect the true cost of what a facility will give rise to. By use of the choice awareness theory, choice eliminating mechanisms are found as to why there is currently only one new product that offers a reduced tariff on the transmission grid in review at Forsyningstilsynet. This new product called "limited access" is found to not reflect what a PtX facility will give rise to as it only offers a reduced transmission tariff, and not a reduced system tariff. In the analysis it is shown that this is unfair, as a PtX facility can offer services to the transmission grid that justify a reduction of the system tariff.

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1.0 Problem area

1.1 Climate Mitigation

Since the industrial revolution, the global average surface temperature has risen by 0.87±0.12 °C. This warming is already resulting in serious consequences for both humans and ecosystems. These consequences show up as extreme weather events like rise in sea levels, new challenging patterns in precipitation and changes to the timing of seasons. [4]. To prevent a scenario of catastrophic droughts, flooding, and hurricanes, most countries and states have signed the Paris agreement that obliges them to keep the rise in temperature at a maximum of 1.5 °C above the preindustrial levels. [5].

From 1990 to 2015 the GHG (Green House Gas) emissions related to energy has increased by 12,6 Gt CO_2 equivalents. In all other sectors the increase in GHG emissions was 2,7 Gt CO_2 equivalents in the same period. [6]. As fossil fuels still are the main source of energy, combustion of them is the main contributor of human affected climate change. To reach the goal of temperature rise in the Paris agreement drastic measures in the energy system is necessary, on the demand side this implies electrification of the energy end use and increasing the share of renewable energy in the production [4].

1.2 Danish climate action goals

To take responsibility and live up to their commitments the Danish government has taken through global initiatives like the Paris agreement and the Kyoto protocol, plans and goals have been made to accelerate the transition. In 2011 the government set the goal of becoming a fossil free nation by 2050. To achieve this goal, it focuses on further expanding renewable energy production, investing in energy efficiencies, and research in new and improved technologies. [7]. In 2019, the danish parliament agreed to commit themselves through a binding climate law to reduce emissions by 70% within 2030 compared to 1990. It is stated that the climate goals must be met in a cost-effective manner, that ensures the business development progress in a positive manner, and the competitiveness of Danish business is kept in a strong position. [8]. The independent climate council have assessed the actions taken by the government to reach the 70%-goal and have concluded that without further action only 1/3 of the needed reductions are going to be realized, and that significant emission reductions are necessary. [9]. To reach the goal, further action must be taken, and it is important for lawmakers to be aware of the consequences of their choices. This thesis will investigate one remedy the government can utilize in order to speed up the necessary reductions.

1.3 Fossil fuel energy system

Denmark has the advantage of a large wind resource and have had a focus on increasing the share of renewable energy in the Danish energy system. Between 1990 and 2019 the production of renewable energy has increased by 288%, where especially electricity produced in wind turbines have had a major impact. According to the EU's accounting method, the renewable energy content in the Danish energy mix was 36,7% in 2019, which is an increase from 35,7% in 2018. Despite the growing share of renewables, the remaining fossil part is still the dominating source of energy. [10]. In the sectors where decarbonization is cheapest and technically easiest, the transition is prioritized first as it yields the largest reductions in emissions. But there are sectors which are heavily reliant on fossil fuels and where the transition is neither cheap or easy, they include sectors like cement, agriculture, iron, chemicals, plastics, and heavy-duty transport. Promising technologies are arising to solve these issues, but regulatory incentives must be put in place to accelerate the decarbonization. [11]. Therefore, this thesis investigates how one regulatory incentive could be used to stimulate the technologies and the market that are going to decarbonize hard to abate sectors.

To decarbonize the transport sector, the European union have introduced blend in demands of biofuels in gasoline and diesel, this have proved to be an efficient measure to reduce emissions. The most efficient strategy for decarbonizing the transport sector is to directly electrify it [12], but not all parts of the transport sector is technically feasible to directly electrify yet. The planning practice until now has mainly been to gasify busses and truck fuels and use the blend in demands [13]. Combined with the large increase in biomass fired powerplants throughout Europe, the stress on the biomass resource have been causing concern from environmental organizations on both its socioeconomic and environmental negative impacts, and the risk of creating a bioenergy lock-in. The categorization of biomass as a 100% renewable intercarrier is too simplistic, this becomes obvious when taking land use change into account and the emissions from them. This result in hard-to-abate sectors not being truly decarbonized, even though all the fossil fuels are replaced. Bioenergy has been depleted of its potential [14], and the domestic sustainable biomass limit has been named the most significant obstacle to transition to a truly carbon neutral and fossil free energy system. [15]. This thesis will seek other alternatives to reductions than bio-based sources.

Another difficult challenge when tackling the issue of decarbonizing the energy system is the flexibility and storage capabilities of fossil fuels. It is difficult to create the same features in a 100% renewable energy system. The current danish planning approach of dealing with fluctuations in production and the mismatch between demand and production is to export the excess electricity to neighboring countries, but this solution has its drawbacks as well. The strong western wind that is utilized to produce most of the fluctuating electricity in Denmark is also present in the neighboring countries simultaneously, and they are also investing in large capacities of wind turbines. This result in the price of electricity from wind turbines to often be low, which makes the investment in wind turbines a worse business case than it could be [16]. By reducing the economic benefit of investing in renewable electricity production the transition to a fossil free energy system is slowed which will have negative consequences for the climate and the environment.

1.4Electrofuels

One solution to the beforementioned problems is electrofuels. The core material in electrofuels is hydrogen, in order for it to be a carbon neutral product it must be produced either with the traditional method of either coal, or more common, natural gas, with a carbon capture and sequestration (CCS) system fitted to the production, or with electrolyzers. Alternatively, gasification of biomass can produce hydrogen by converting solid biomass into gas with a specific gasification agent. The terminology of hydrogen produced with CCS is "blue hydrogen", and hydrogen production via electrolyzer or with biomass is called "green hydrogen". State of the art of current hydrogen production is considered thermochemical processes based on fossil fuels which is called grey hydrogen [17].

The benefit of blue hydrogen is the short-term lower cost of production and the benefit of green hydrogen is the system services large scale electrolyzers can provide for the grid. It is expected that green hydrogen via electrolysis can be produced at a lower cost than blue hydrogen in the early 2030's [18]. Green hydrogen via biomass is according to IEA Bioenergy able to be produced at a price of 2,7 EUR/kg H2, which is competitive with traditional grey hydrogen [18] [17]. The argument against hydrogen from biomass gasification is the sustainable depleted resource [14], and therefore alternative pathways needs to be explored.

Utilization of renewable electricity to produce green hydrogen is a topic that receives a lot of attention due to its large potential to decarbonize the hard to abate sectors. By combining green hydrogen with carbon dioxide captured from the flue gasses of a bioenergy production unit it is possible to produce hydrocarbons that can be refined into the desired derivative in a similar manner as is done with oil to produce fossil fuels. By capturing the carbon from a carbon neutral point source, the new end product is included in the carbon loop and are therefore reducing the carbon footprint of the fuel. The method of accounting for the reduction in emissions is defined under Innovation fund projects by Annex A [19]. The degree of carbon neutrality is in the range of 85%+ [20]. Not all electrofuels require carbon as a resource, like green ammonia, the hydrogen is reacting with nitrogen produced at the site. Common for all electrofuels is that they are a much more expensive alternative than continuing to use fossil fuels for the end user. Depending on the end product the price difference varies between 2-5 times the fossil alternative. [18]

The Renewable Energy Directive II by the European Union introduced in 2018 a new term called "*renewable liquid and gaseous transport fuels of non-biological origin*", referring to electrofuels aimed at the transport sector. The directive outlines vague guidelines for how the fuels can be certified as green fuels. Two main criteria for the certification are temporal and geographic correlation between production of electricity and production of fuel, and the timing of the establishment of the renewable electricity production unit. [21]. The latter one referring to the need for additionality in renewable electricity production. The issue of correlation between productions, have been interpreted by the Danish TSO Energinet, and they have outlined a series of connection models of the Power-to-X (PtX) facility that allow for certification of the end production, but as it is only an interpretation no certainty can be made for the ability to certify the fuels from this paper [22]. The European union have made a delegated act to standardize a certification method of renewable electricity used to produce electrofuels. This standardization is due to be published before December 31st, 2021 [23].

In late 2020 a group of researchers conducted a meta study on the national hydrogen strategies, including the EU strategy, published in the past few years. The conclusion of the report is that green hydrogen will play a significant role in decarbonization of the energy system, and that the ambitions for ramping up electrolyzer capacity is large. The strategies started to emerge in 2017, which implies that the interest for green hydrogen is fairly new [24]. The applications of hydrogen suggested in the strategies is found to be partially in line with projections of cost and appropriate applications of researchers from Aalborg University [25]. More recently the technological development within batteries have progressed faster than anticipated, and therefore hydrogen is no longer seen as the only viable option in all heavy-duty transportation [26].

Hydrogen production via electrolyzer is highly reliant on cheap renewable electricity, and in Denmark this resource is available as a result of the offshore wind turbine adventure that placed Denmark in the forefront of the development. This development was made possible by foresighted politicians that made the regulatory framework for the development, according to certain voices, the same needs to be done for PTX to make it the next export adventure [27]. On the distribution grid, there have been differentiated and variable tariffs for several years. [28] The reason why the transmission grid does not have them is not clear, but one explanation can be that the need has not been there in the past, and the distribution grid operators saw the need for them earlier. [29] [30]. Now the need is present due to the expected electrolyzer capacity, and to do so smart, it is necessary with incentivizing remedies for differentiated consumption, and it is essential to review the tariff structure [31] [32]. As Energinet has only reported one method for incentivizing tariffs on the transmission grid, the argument of this project is that it is important.

A lot of the technology that electrofuels rely on is not new, but rather a new combination of existing technologies, therefore it is rather predictable what the Capital Expenditure (CAPEX) of the production facility is going to be. It is more interesting what the OPEX of the facility is going to be as the electricity price has the largest impact on the selling price of the end product [18]. Both uncertainty of the ability to certify the end product, and the overwhelming production cost is obstacles for the technology that is limiting the rate at which it is contributing to emission reductions. As the European Union is working on a method of accounting for the renewable electricity used in production, this thesis will investigate tariffs as one method of reducing the OPEX of a facility and thereby incentivizing investments in the technology.

1.5 Strategies to reach a fossil free energy system

Several approaches could be chosen to decarbonize the energy system, and one approach does not necessarily eliminate the other. Electrofuels are criticized by NGO's for not being as green as they are portrayed in the media, putting more unnecessary strain on the biomass resource, and stressing the ecological environment by building more energy production units than necessary. Instead, a drastic reduction in consumption of fuels by consumer habit change is proposed, or negative reductions by carbon capture and storage [33] [34]. A study by a research group at Forschungszentrum Jülich have concluded that accounting for life cycle emissions on a PTX-facility is important, as this knowledge is crucial in order to compare different technological solutions, and if a production facility is utilizing renewable, and sometimes surplus electricity, and the carbon source is bio-based, the end product can be justified as a green product [35]. The interest organization "Danish Energy" states that electrofuels are going to be unavoidable to reach the 70%-reduction before 2030 [18]. Furthermore, a research group from Aalborg university in collaboration with The Danish society of engineers (IDA), state that in order to transition to a carbon neutral energy system before 2045, electrofuels are part of a technical and socioeconomic sensible planning approach [32]. According to Fragiacomo, the best practice approach is probably a combination of consumption reduction and technical solutions like electrofuels. But taking in to account the very low overall efficiency of electrofuels, it will make sense to reduce the production to what is absolutely necessary. Otherwise, the risk is that the energy system becomes unnecessary inefficient and electricity production units are stressing the environment without any purpose [36].

This balance between incentivizing fossil free fuels, and not making the business case too profitable for investors is not easy for law makers to find, and at the same time it can be an unfortunate outcome if they "pick the winner" in the technological development race by promoting it. One remedy that can be utilized to stimulate the technological development and facilitate the green transition is development of a strategy on

Power-To-X (PTX), in combination with a revision of the tariff structures. [18] [32]. The way the electricity tariffs are structed today all the expenses of the grid are socialized across the consumer categories. However, an argument could be made that this is not in coherence with the electricity utility act that states:

"Pricing of their services must happen on reasonable, objective and non-discriminating criteria, for what costs the individual buyer category give rise to" [37].

Since there is a mismatch between the current tariff structure and the electricity utility act, the argument of a need for a revision to the current structure is strengthened.

1.6 Summary

Climate mitigation is of great importance, and mitigating emissions from the energy system is unavoidable if the national and international goals are to be met. The Danish government have committed themselves to decarbonize the Danish energy system and are therefore faced with difficult challenges, hard to abate sectors are going to be one of them. Electrofuels are most likely going to be one of the answers to the challenges, but they are still significantly more expensive than their fossil counterparts. One of the remedies the Danish government have at their disposal is tariffs, and this thesis is going to investigate how they can contribute to accelerate the share of electrofuels in the Danish energy system.

2.0 Problem formulation

Electrofuels is in general not competitive with fossil fuels, therefore they are likely not to be produced, but without their alternatives to fossil fuels society will not reach the climate goals. Several actors highlight the need for a new electricity tariff structure that reflect the true cost of what hydrogen production via electrolysis connected to the transmission grid will give rise to. [38], [18], [39], [22], [32]. The purpose of tariffs on the transmission grid is to cover the cost of operation and maintenance of the transmission grid. However, the tariffs do not reflect the true cost of the consumer category, which makes the existing flat structure not compliant with both the electricity utility act, and international regulation further handled in section 6.0. The flat structure will result in unfortunate consumption patterns and does not incentivize consumption at times where the grid, society, the green transition, and investors would benefit from it, resulting in favorable conditions for some at the expense of others.

Energinet is as of now only handling one model for a new tariff structure [2]. A new rate of tariff is only expected to be part of the solution, and more tools may be used to solve the issues at hand. This thesis investigates an alternative tariff rate as a remedy in incentivizing investments in PTX. Therefore, the following questions occur:

What is the appropriate electricity tariff rate, reflecting true cost for PtX as a consumer category connected to the transmission grid, and how does alternatives compare when focusing on criteria in the electricity utility act §73, levelized cost of energy and abatement cost?

- What regulatory framework are an electrolyzer and Energinet subject to?
- How is the current tariff structure and what is an electricity tariff rate that better reflect true cost of PTX as a consumer category?
- How does the tariff structures affect the levelized cost of energy and abatement cost?
- How do the rates compare on criteria from the electricity utility act and cost?

2.1 Scope of project and research design

The hard to abate sectors are in dire need for alternatives to their large fossil fuel dependence. As section 1.4 outlines, electrofuels are likely to be part of the solution to this problem and section 2.0 states, a barrier for the transition is the current tariff structure. This thesis investigates how the current tariff is affecting the levelized cost of energy and the abatement cost of a PTX facility, and what rate a tariff that reflect what cost a PTX as a consumer category gives rise to for the transmission grid should have. The project is reliant on expert interviews that have been used for pricing of cost elements of the tariff, for expert opinions on choice eliminating mechanisms, and for alternative production pathways. Furthermore, the project is reliant on the technology catalogue for calculations exemplifying the economic effects of a new rate of tariff. The new tariff proposed in this project is only part of a solution to promoting PTX as a technology, and more remedies might be necessary to introduce to make the technology competitive. The project delimits itself from modeling of the electricity grid. Further it does not handle tariffs on the distribution grid, or other utility services. There is an intersection between the green transition and the true cost for the transmission grid to operate a PTX facility, it is proposed that this common quantity is exploited as one remedy to reach common beneficial outcomes. This common quantity justifies the price discrimination of the suggested tariff rates. Figure 1 illustrates this intersection.

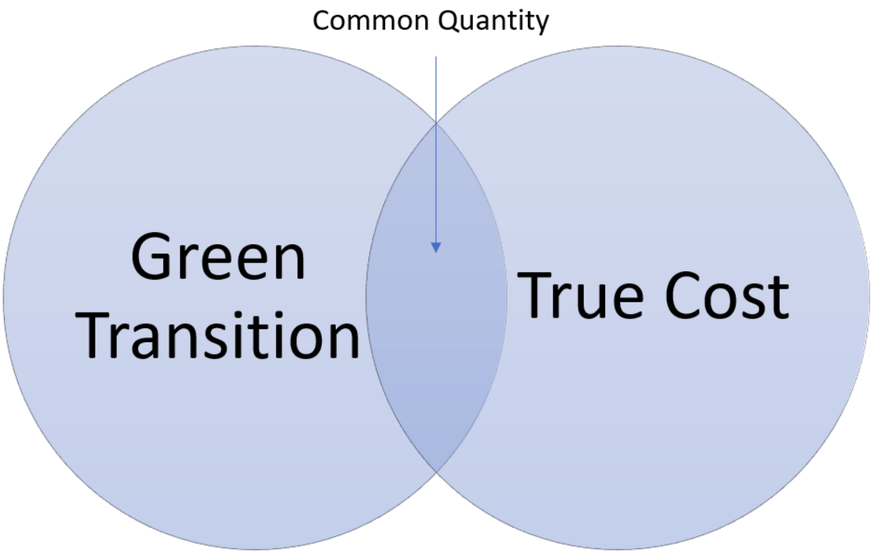


Figure 1 The intersection between the green transition and true cost

Figure 2 illustrates which analysis and correlating sections answers the research questions from the problem formulation.

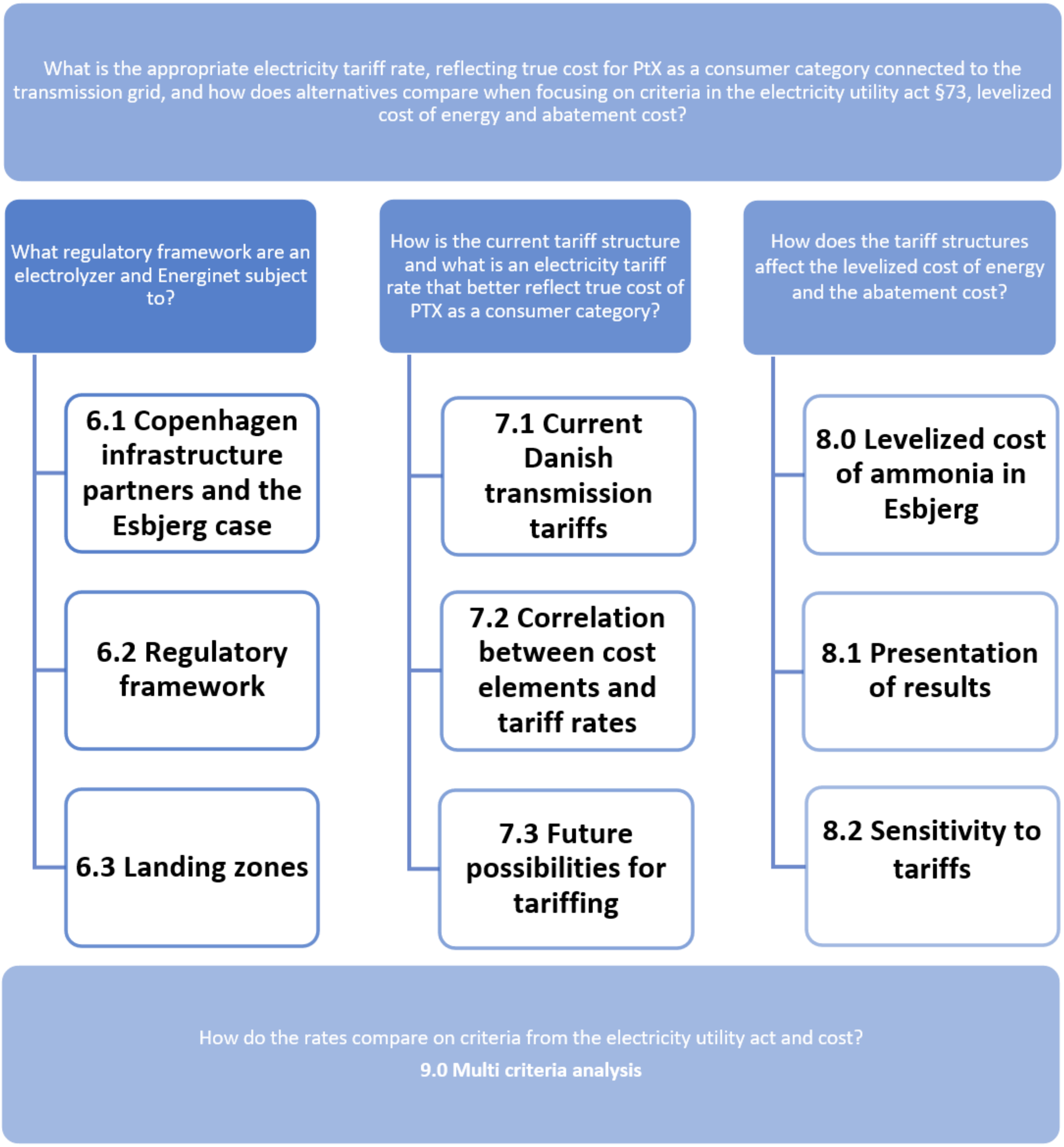


Figure 2 Research design

3.0 Theory of science

In scientific realism, generativity is a key aspect because it revolves around the methods that are used to attain results and reach a conclusion that will be duplicated if another researcher were to take the same approach in a similar case thereby achieving representativity. This is how scientific realism is different from instrumentalism [40]. It is trough scientific realism the world is perceived in this project, seeking to add new knowledge to the community and guide the recipients. Scientific realism has its origins in empirical approach positivism, in which the researcher handles data from the real world. The job as the researcher is to represent the data in the most objectively way possible and be unbiased. This allows the data to speak for itself and decisions taken based on the data to be taken on as fair a basis as possible.

Realisms best argument for its justification is the ability to accurately predict phenomena in nature, and the constant adding knowledge by doing so. Researchers arguing for constructivist epistemology would argue that it is not enough to predict phenomena in nature but also to ask the underlaying why to get a deeper understanding of what is happening. [41]. The aim of the project is to create a methodology that acts as a guideline for how to confront similar issues by presenting data on the most objectively way possible, reaching representativity and awareness of, and the consequences of, different choices.

4.0 Theoretical framework

4.1 Choice awareness

In his book "Choice awareness and renewable energy systems" Henrik Lund present the choice awareness theory and portray how radical technological change can be obtained. To reach radical technological change, two or more of the five dimensions defined by Müller and Remmen and later the 5th dimension added by Hvelplund, must be changed [42] [43]. These five dimensions are technique, organizations, knowledge, products, and profit. In this context organizations consist of both physical systems like business, non-governmental organizations, administrative units, companies, and the less physical informal and formal rules. To reach the goal of a 100% renewable energy system, the transition represents a radical change where few large investments into fossil centralized energy production units will need to be substituted with many renewable decentralized energy production units. A change in the organizational setup must be obtained before this transition can be successful as the institution usually prefers traditional technologies over newly introduced ones. [44]. The establishment might try to maintain the current discourse in planning by suppressing information about choices, thereby creating a *no choice*. A true choice is defined as the choice between several options, and a false choice is the illusion of a "choice" where only one option is presented.

In the choice awareness theory, there are two theses. The first one is aimed at the established political power used to counteract the transition by eliminating choices. The discourse of existing institutions affects the process and can hinder radical technological change. This is done with choice eliminating mechanisms, that will show that the proposed alternative is not relevant, does not comply with requirements, or with methodologies that are formed in such a way that the alternative will not be economic feasible. This project challenges Energinet in only handling one model for a new tariff structure.

The second thesis is revolving around the importance of enlightenment in the community of choices and that they do exist. The thesis argues that society benefits from having several alternatives to choose from, thereby raising choice awareness. There are three main means to raise choice awareness:

1. Promoting concrete technological alternatives
2. Promoting feasibility studies which includes political objectives
3. Promote description of remedies that could be used to advance certain technologies.

The methodology of the second theses is used for raising awareness of the alternatives that exist. The first step is to describe the different solutions, in this project it is the new proposed tariff rate. In order to compare the alternatives, the central parameters must be corresponding. Further, the more precise and concrete the suggestions are, the larger the chance of the suggestion to be taken into consideration is. [44] O'Brian argues for the importance of alternative assessment by describing the pros and cons of the alternatives [45]. In this project a comparison is done in the multi criteria in section 9.0.

In spite of a technical or socioeconomic solution shown to be superior to the existing, it is not certain that the alternative will be chosen due to the institutional context. Therefore, feasibility studies are used to raise awareness and enlighten the public about alternatives and the barriers hindering their implementation and identify measures to be taken to overcome the challenges. This project should not be seen as a full feasibility study, but rather as a screening of consequences of a change in tariff rates and is meant as a tool for enlightenment of the choices available. Energinet have published an action plan for PtX, where it is stated that:

"… it is necessary to continue the studies on whether even more flexibility in both access to the grid and associated lower payment for using the grid is the best way overall to expand the market for PtX." [39].

This thesis will add knowledge to the scientific community, decision makers and actors with interest on how alternative tariff rates will affect the levelized cost of energy and abatement cost of PtX facilities. This is considered to be in line with the theoretical framework of the thesis. The conclusion will not answer if the alternative solutions will be the best way overall to expand the market but provide as objective data as possible to the researchers seeking to answer this question. A new rate of tariff for a consumer category "PtX", will only be part of the solution, and should not be seen as the only alternative or the solution to all issues regarding the green transition. If the tariff suggested in this project is accepted by lawmakers, it is the new status quo, and it must be challenged. One must always seek to improve the current situation, and by doing so it is important to challenge discourses and power.

Discourse and power

A discourse in this context is an institutional founded way of thought, a social framework that defines what can be said about a given subject. It consists of a limited number of statements of which one can define the conditions of possibility [46]. Different actors can have different discourses about the same subject, which means that the subject is affected in different directions according to the actor's agenda. In the context of this project, one discourse could be that it is a success criterion that the law must be complied with when making new regulation and setting new rates of tariffs. Another discourse could be that we should focus on the common quantity between the green transition and true cost, illustrated in figure 2. The agenda of an actor can be pushed on a decision-making body by the power possessed by the actor. As Phillips and Jensen define power *"Power is seen as the possibilities of actors to attend to their interests in relation to the* *allocation of goods and burdens in society"*. Often, the execution of power will already happen before the decision-making process takes place. In the context of choice awareness and this project, an example could be Energinet not having several alternatives to the current status quo of tariffing, stated in another way, they have executed their power by only presenting one alternative to a new tariffing model.

4.2 Price discriminating theory

In a free marked, rational behavior by the individual can sometimes lead to non-rational outcomes for society leading to an inefficient utilization of a service and lead to socioeconomic distortion or inappropriate consumption of resources. This phenomenon is called a marked failure. [47] One of the solutions to this failure is a price discrimination among consumer groups based on certain specifications, resulting in differentiated pricing based on age, location, or other characteristics [48]. Before economists, engineers saw the advantages in differentiated pricing across consumer groups to cover the cost of operation and maintenance of a service, with the first service to experience price differentiation being public transportation. The argument for introducing differentiated payments was the utility to which certain groups of the population was able to pay for tickets. [48]. An extension to this addresses the rationing of demands in relation to capacity constraints. The differentiated tariffs attempt to distribute load on the installed capacity, as different consumers give rise to different cost of providing the service by reducing the load that a consumer puts on the system [49]. In transportation services this is done by restricting the timeframe of which certain consumers can use the service in return for a lower fee, and by increasing the fee for consumers using the service during rush hours. The theory has more recently been modified to provide the service of "sequential screening", which allows a consumer to pick between several optional tariffs, and from that calculate their desired need for consumption. The purpose of doing so is to cover costs and simultaneously fulfill goals set by the regulators [48].

It is no easy task finding the optimal differentiated tariff, but the accessibility to different possible products from the provider are crucial for a fair treatment of consumers dependent on the service while covering costs and fulfilling goals set by the regulators [48]. Presentation of different alternatives to provide solutions for a certain challenge and fulfill goals set by regulators is found to be in accordance with the choice awareness theory, and there exists synergy between the theories.

5.0 Methodology

5.1 Literature review

A literature review can be described as a systematic approach to collect, manage, and compare data for research. By synthesizing the data collected it can become apparent what state of the art within the chosen topic is, and where there is a need for further research. [50] Different variations of systematic literature review methods exist, each connected to different research questions. These approaches include semi-systematic and systematic approaches.

In section 8.0 a systematic review has been used to extract the necessary data from the technology catalogue. These have been used to calculate the economics of a system that resembles the facility planned in the Esbjerg case, further described in section 6.1. Exploratory and semi-structured literature reviews have been used to broaden the knowledge on issues regarding climate change, tariffs, and regulation.

5.2 Interviews

This thesis is reliant on expert interviews and have been used exploratory to close in on the problem, to gather information on ways to approach the issue, and to find alternatives. This is done to raise the choice awareness of the author and to deliver this knowledge to the scientific community. Semi-structured interviews have been done to answer questions that are used to qualify the discussion. Data gathering consist of interviews in this project and is kept in the method section for the sake of ease for the reader. Resumes are written as a representation of what the interviewed have said.

All resumes of interviews have been reviewed and approved by the interviewed contributors.

Luis Boscán

Luis is an economist with a PhD from Copenhagen Business School. He has formerly been a lecturer on both Danish Technical University, and the University of Southern Denmark. Besides this, he is a former employee of the Danish utility regulator Forsyningstilsynet.

The interview is an explorative expert interview with the purpose of gathering information on the relation between Energinet and Forsyningstilsynet, gather information on tariff theory, and qualify the discussion on the term true cost.

Resume of interview:

Energinet is a natural monopoly, which means that the socio-economic cost of producing its output (transmission infrastructure) is lower in the hands of one entity than what it would be under competition. From the perspective of neoclassical economics, monopolies are inevitably less efficient than a competitive result, but we have to live with it. To reduce the inefficiencies that they are prone to, they are regulated. At present, Energinet is regulated under a cost-plus framework. It is expected, however, that Energinet will transition into an income-cap framework.

With regards to tariff design, the Danish electricity utility act has very broad articulations, but it also has very concrete principles and concepts. When the Danish Utility Regulator (Forsyningstilsynet) receives a method description from Energinet, they will review it and make sure it is in line with the law, while being in close contact with Energinet to understand the content of any proposal that Energinet submits. It could very well be that principles as true cost (cost reflectiveness) and its practical implementation are discussed during this process.

It is very difficult to assess whether or not the tariff in the model "limited network access" lives up to the principles of cost reflectiveness. No matter what, and due to the collective nature of the electricity network, we cannot avoid socializing tariffs, but the green transition is a political choice, and one of the remedies one can use to accelerate the transition is a lower tariff for certain consumer categories. One possible argument to justify lower grid costs for PtX facilities is that they save grid expansion cost.

Subsidies will always create a distortion but can be justified if they solve a marked failure, in this case climate change.

Daniel Macchini Schrøder

Daniel is a former it-developer from Energistyrelsen and is currently working as an IT-system administrator.

The purpose of this interview is to get a technical expert's opinion on the difficulties on developing and managing a system for tariffing that will follow the criteria from the electricity utility act about true cost, and yet be simple. This is done to have an argument against the possibility of a representative from the establishment arguing for the complex or impossible task of developing and managing a database that can handle a new tariff structure. Besides that, it will allow nuance in the discussion about the dilemma between true cost and simplicity.

Resume of interview:

With precaution, it should be a relatively simple task to develop and maintain a database that will be able to charge the consumer the correct tariff. With more attributes and criteria to the database, the complexity will rise, and the processing power and manpower is needed to operate the database. In a scenario with different tariffs to all the consumers, the task would be enormous, but in a scenario with 5-10 consumer categories, it will be manageable.

There might be some regulatory issues with accessing data or charging costumers that I am not aware off, but the technical task is not impossible, it might be challenging, but definitely not impossible.

Hans Henrik Lindboe

Hans Henrik is an Engineer from the technical university of Denmark, with further education within economics. He has formerly been employed at Energistyrelsen as a project manager and at Energinet where he was vice president in the department of planning. He is currently a partner and head of the board at Ea-Energianalyse.

Hans Henrik has comprehensive experience within analysis of the utility value of investments of the Nordic transmission net, and the economic conditions of integrating large portions of renewable energy in the electricity system. [51]

During spring of 2021, Hans Henrik has been acting as a co-supervisor on this thesis and have contributed with value insight into the dynamics of the electricity system and tariff structures. In the analysis on the flexible demand tariff model, section 7.3.2, Hans Henrik have been the main contributor to assessments of pricing of cost elements. [26]. The contribution of Hans-Henrik consists of several meetings and correspondences regarding the thesis. He has answered questions on the history of tariffing, provided insight in the interpretation of laws. Furthermore, he has provided data on electricity prices and helped form the analysis. There is no resume of the correspondence with Hans-Henrik as he has engaged in several meetings during professional meetings, and in less formal meetings only in relation to this project.

Morten Tony Hansen

Morten is a senior consultant at EA energy analysis and is considered an experienced bio-energy expert.

The purpose of this exploratory interview is to assess the alternatives to producing hydrogen from electrolysis, or other bio based alternative methods of decarbonizing the hard to abate sectors. This is done to further qualify the discussion, and to create awareness of alternatives not further handled in this project.

Resume:

According to Morten, the bio-energy resource is not depleted of its potential as other research suggest, and effort should go into solving issues regarding biodiversity and LULUCF rather than abolishing the utilization of biomass. By using biomass for gasification for production of e.g., methanol, the resources might be utilized with higher efficiency than other pathways. Another main argument for the use of bioenergy for abatement of CO_2 or production of electrofuels is its low cost. Still, the best and often cheapest way of reducing emissions is by reducing the demand.

In regard to finding the best application for biomass versus hydrogen, Morten suggest the course of action to answer the question is to investigate what is technical feasible, economy, space, supply chains, and especially the efficiency is important.

David Hartz

David is a chief consultant at Energinet with responsibilities within economy and regulation.

The purpose of this interview is to qualify the discussion by getting an opinion on the causal analysis and whether or not the cost found is seen as a true cost by Energinet.

Resume:

The model "limited access" has been in the process of review at Forsyningstilsynet for most of a year now. Hopefully, it will be approved soon, but the reason for the late answer, is probably the lack of resources at Forsyningstilsynet.

David acknowledges that PTX facilities are probably flexible, but as there is none to very little DK experience with actual behavior. The facilities will be dependent on an electricity grid that are available to deliver the demand they require at all times. They should also pay their share collectively as all other consumers but "limited grid access" will probably be relevant for them. In addition, the cost of the system tariff can be offset by income made in the ancillary services market. He does agree that it can be difficult to balance the mismatches there can be with several principles of tariffing. It can be difficult to assess who gives rise to cost that should be covered by the system tariff, but it is more and more the producers of electricity that give rise to those cost. The issue is that Energinet is bound by EU-law to only tariff producers a certain amount, and the cost must therefore be socialized on to consumers, it would be a higher degree of true cost to charge the producers more.

On the issue on why energinet does not have differentiated tariffs, when the DSO's have, David is not sure, but in his opinion, it might be because they saw the need earlier.

Martin Groth

Martin is a chief consultant at Forsyninstilsynet and is working within their center for analysis and have worked with tariffs.

The purpose of the semi structured interview is to present the findings in the analysis to an authority, and to further qualify the discussion. It should be noted that the opinions stated in the interview are not the official opinions of Forsyninstilsynet, but rather personal opinions by Martin.

Resume of the Interview:

The approach of the causal analysis was approved as a valid method of estimating the true cost of what a PtX facility will give rise to. It was underlined that it is crucial that geographic differentiation is permitted if the assumption of the causal analysis is going to be valid. On the issue of why the transmission net does not have differentiated tariffs, the answer was not clear, but arguments of technical feasibility and bureaucratic obstacles were highlighted.

When Forsyningstilsynet reviews a method for tariffing, they do it on the basis of the following criteria: Reasonable, Objective, Non-discriminating, True cost. These criteria stem from the electricity utility act, further addressed in section 6.2.3.

5.3 Data management

5.3.1 Electricity price

The electricity price is based on modelling and projections of the energy system done in the modeling software "Balmorel", from a projection in the year 2025 an electricity price profile is given and can be found in appendix 1. The data was provided by EA Energianalyse, and a distribution curve illustrates the price in figure 3.

Figure 3 Distribution curve of electricity price in 2025

To estimate the electricity price, EA Energianalyse have provided an electricity profile that contains projections of the electricity price. It is assumed that the facility will be operational in the 4500 hours where the electricity price is lowest. This results in an average electricity price of 34,04 EUR/MWH. Further information hereabout can be found in appendix 1.

5.4 Causal analysis

Energinet's pricing does not take in to account the special needs of certain costumers but focus on having high security of supply and socializing of cost. This leads to certain costumers paying for services they do not use and no incentive for flexible demand. In section 7.2, the aim is to find the causal contribution between the expenses of operating and maintaining the transmission grid and the tariff rates.

It is notoriously challenging to determine the relationship between cause and effect, and it must be assumed to be two distinct phenomena. The classical example is the cause and effect of smoking. It is impossible to conclude that there is a direct causal effect between smoking and lung cancer. It could be that there exists an unknown genetic mutation that makes persons prone to lung cancer crave nicotine, or that nicotine craving is an early predictor of lung cancer. Could this correlation be made, it would be an *actual causation.* To overcome this challenge, the term probabilistic causation is used to describe a phenomenon where cause and effect is most likely present, in another way, the probability of the statement being true is higher than chance. This leads scientists to conclude that within probabilistic causation, smoking does cause lung cancer. [52]. The term probabilistic causation is also used in this project as the way to justify uncertainties between the correlation of tariffs cost elements and tariff pricing.

The model, illustrated in table 3 and 4 recreates Energinets pricing of tariffing and is used as justification of putting a price of the new proposed tariff in section 7.3.2. The data about Energinets cost and income from the transmission grid is found on their website [2], and the data on the electricity consumption is from the danish energy agencies basic projection [53]. The cause and effect between the cost elements and the tariff rate are found within probabilistic causation and further calculations are found in appendix 1. The method of estimating this probabilistic causation is assessed to be a valid method for the purpose of this project by Matin Groth, section 5.2.

5.5 Calculations

This section presents the economical methodology and variety of calculations used to conduct the later described multicriteria analysis and comparison on the two tariffs models. By using the following methodologies, it has been possible to estimate cost of fuel and difference in pricing between fossil and green alternatives.

5.5.1 Cost elements of tariffs

To calculate the income of each cost elements the value of 5.0 billion DKK, which is the total yearly cost of operating and maintenance of the electricity grid is multiplied by the percentage stated in the left pie cart of figure 8. The cost of the element is converted into a cost pr kWh by dividing the cost of the element by the total electricity production of 33,3 TWh, which is Energistyrelsens yearly inventory projection of energy consumption [53].

5.5.2 Economic calculations

Levelized cost of energy

For the calculations of production cost of electrofuels, levelized cost of energy (LCOE) is used. This is done to consider all costs during the lifetime of the plant. The investment cost is distributed on the lifetime of the facility, and the discount rate is considered. To follow the ministry of finances guidelines, the discount rate is set to 4% [54]. The formula for calculating LCOE is as follows:

$$LCOE = \frac{\sum_{t=0}^{n} \frac{R_r}{(1+i)^t}}{Lifetime} / energy\ output$$

Where R = balance between inflows and outflows in a period t. And i = the discount rate. And finally, t = time periods. [55]

Components

To determine what elements the production facility consists of a combination of “Electrofuels in the transport sector” [56] and “Technology data for renewable fuels” are used [57]. The technology catalogue does not state values for investments in 2025, and as the calculations are done for the year 2025, the average value between the 2020 and the 2030 value are used for investment cost.

The components in the system are as follows:

$$\text{Total cost} = \text{investment of electrolyzer} + \text{O\&M of electrolyzer} + \text{investment fuel synthesis} + \text{O\&M of fuel synthesis} + \text{cost of electricity} + \text{tariffs} - \text{sales of heat} - \text{sales of oxygen}$$

Abatement cost

To calculate the cost of abating one ton of CO_2 by the production method used in this project, the production cost is compared with the fossil alternative price. The difference in cost divided by the amount of abated CO_2 is the abatement cost. This is exemplified by the following formula:

$$\frac{Cost\ of\ renewable\ alternative - Cost\ of\ fossil\ alternative}{Ton\ of\ abated\ CO2} = Abatement\ cost$$

The price of fossil ammonia is varying from region to region and every year, it is highly reliant of the price of natural gas and is therefore difficult to value. In a study from 2020, where several actors with interest in green ammonia by electrolysis collaborated to assess the future possibilities for green ammonia the price is projected to be 250 USD in 2025-2030, and in this project this value is used. [58]

To estimate the emission factor of fossil ammonia, that was used to calculate the abated amount of CO_2, a meta-study of several studies was done as this value is of high significance when estimating the amount of CO_2. This meta-study was summarized in table 8.

5.6 Multicriteria analysis

The models presented in this project has different characteristics that makes them better at solving a task than others. In order to compare the different models, the multi criteria analysis method is used. It enables for – in opposition to cost benefit analysis – comparison of criteria that are not monetary, but rather qualitative. These criteria are assessed on a scale or with a point system. It is important to note that it is not true or fair to summarize the points given to the models as the criteria might not be weighed in the same way, and different receivers of the result might not have the same opinion of what the weight of each criteria is. In a decision-making process, this method makes for an overview that reflects the relevant aspects of the decision. [59]

5.6.1 Qualitative criteria

The electricity utility act §73 is built around 4 key principles, that are used as the qualitative criteria in the multi criteria analysis as a way to assess the quality of the tariff model and secure compliance with electricity utility act §73 further described in section 6.2.3 [37].

These key principles are listed directly from the electricity utility act §73, and defined for this project as:

- True cost
    - A consumer category must pay the cost they give rise to, not more or less than the expense they give rise to. This criterion is interpreted in a strict manner in this project.
- Reasonable
    - The term non-discriminating is leaning up against the term reasonable and is in this project understood as giving all consumers an equal and fair treatment that will not favor some at the expense of others
- Non-discriminating
    - Defined as a justified treatment of all consumers and an equal treatment of the category no matter their characteristics
- Objective
    - Defined as being loyal to facts and not letting personal opinions or feelings influence the tariffing, while presenting them in a transparent manner.

The abovementioned criteria are the foundation of the assessment Forsyningstilsynet reviews of models for tariffing Energinet seeks to get approved. Therefore, these criteria are also used in this project as the qualitative criteria for assessing the proposed new rate of tariffing in section 9.0.

As the project process problems facing PTX facilities, the assessment will be done with this in mind as the project does not go into depth with other aspects of the electricity grid and does therefore not possess the capabilities to assess the proposed tariffing methods in relation to those aspects.

5.6.2 Quantitative criteria

To assess the effects of the tariff model on the economy of a facility, the levelized cost of energy divided by the total amount of fuel that is produced, measured in MWh, is the criteria that are used. The unit of ammonia is first calculated in EUR/MWh and then converted into EUR/ton as fossil ammonia prices are usually stated this way.

For society it is relevant to know the cost difference in producing the end product between the fossil alternative and the renewable alternative. The price of fossil ammonia is set to 250 USD/ton [58]. This criterion is calculated by dividing the total price difference between the fossil ammonia and the green ammonia with the total amount of abated CO_2. This criterion will enlighten society about the possible extra cost it will create to reach the climate goals pr ton of CO_2 the facility is able to abate. This criterion is also named the abatement cost. [60]. All calculation here about can be found in appendix 1

5.6.3 Multi criteria matrix

The result of the multi criteria analysis is shown in a matrix where criteria are on one axis and models are on the other. For the 4 qualitative criteria a score of 1-3 is given, where 3 is best, and for the two quantitative criteria the value itself is given. The purpose is to summarize the models in a manageable way, but it is important to note that the values in the table cannot be added to find the optimal model.

The template for the multi criteria analysis will therefore look as follows:

Rates / Criteria	True cost	Reasonable	Non-discriminating	Objective	LCOE/Fuel (EUR/ton)	Abatement cost
Rate 1						
Rate 2						
Rate 3						

Table 1 Multi criteria analysis matrix

6.0 PtX and the regulatory framework

The following section will describe the Esbjerg case and the regulatory framework they are subject to. The case is chosen for this project for further discussion and calculations as it is highly relevant in regard to the green transition of the hard to abate sectors, it is a current project, and because the business case is reliant on cheap renewable electricity and tariffs that reflect what the facility will give rise to.

6.1 Copenhagen infrastructure partners and the Esbjerg case

Copenhagen infrastructure partners (CIP) manages funds and specializes in investments in energy infrastructure and especially within renewable energy and other greenfield technologies. They have a long history in investing in offshore wind, energy storage and power transmission. [61]. In February of 2021 they announced plans to build a large PtX facility in Esbjerg in collaboration with market leaders with their fields.

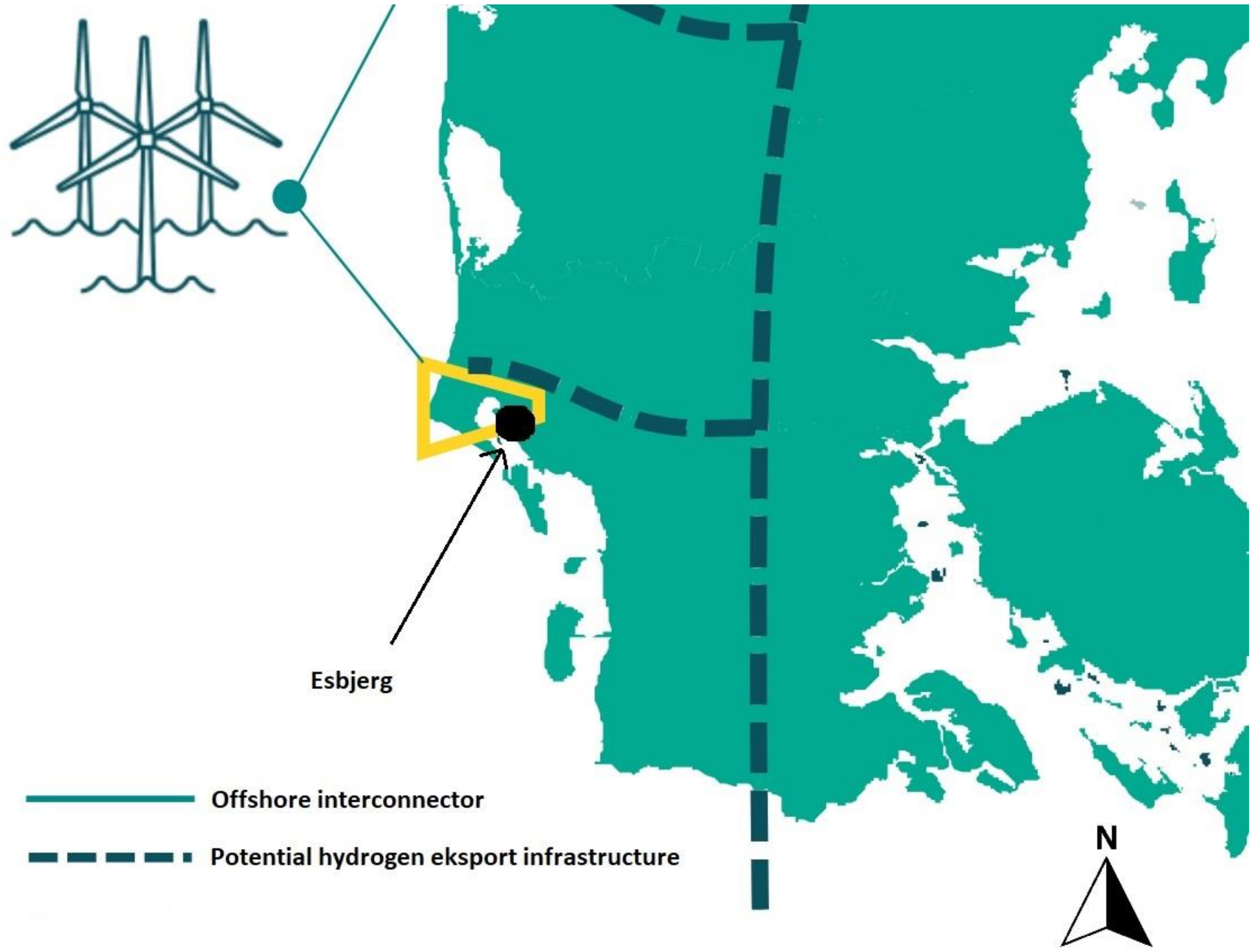


Figure 4 Placement of Esbjerg in relation to the coming North Sea power production. ref: [1] with modifications. Yellow box illustrates a potential location for a landing zone.

The plant is going to be producing ammonia for both the agriculture industry and later the shipping industry. Both sectors are in dire need for alternatives to their fossil consumption as large parts of the sectors cannot be directly electrified. CIP utilize the willingness to pay for additionel cost in the sectors to mature the technology and bring the cost down. The electrolyzer is planned to have a capacity of 1 GW, which will be sufficient to produce ammonia enough to supply all of the Danish agriculture sector with fertilizer, which today is produced with fossil fuels. This will reduce the yearly CO_2 emissions by 1,5 million tons. [62]. The placement of the electrolyzer is seen as a strategic placement in the electricity grid as it will allow the facility to utilize electricity from the coming wind power island in the North Sea, and simultaneously deliver excess heat to the district heating grid in Esbjerg. As it is apparent from figure 4, the North Sea power hub is expected to be landed near Esbjerg.

6.2 Regulatory framework

This following section is going to analyze the regulatory framework that the Esbjerg case and Energinet as the TSO is subject to. The purpose of doing so is to identify the criteria the facility must oblige to in order to certify the end product as green, and to identify what taxes and tariffs the facility is subject to.

6.2.1 RED II

It is essential for the investor to be able to certify the end product as a renewable alternative to a fossil counterpart. As electricity is the main deciding factor in the certification, the regulatory framework needs to be able to facilitate the task of certifying the electricity as renewable. The European Commission adopted and released the Renewable Energy Directive II (REDII) in 2019. It creates a framework for increasing the renewable energy share in Europe. The directive introduces the term *"Renewable fuels of non-biological origi*n" that covers fuels that is an alternative to fossil fuels and that are not produced with biological materials, the new term covers what this report describes as electrofuels. The directive describes the fuels as being produced with renewable energy other than biomass. [63]. The Danish government have still not published an integration of the directive in Danish legislation. One of the reasons for why this has not happened yet might be because the European Commissions have put in action a delegated act to produce a standardization on certifying electricity for production of these fuels. The standardization is scheduled to be published before the end of 2021 [64].

Article 27 in REDII sets the requirements for electricity to be counted as renewable in regard to hydrogen production from electrolysis, but as the directive only specifies the requirements for the transport sector to certify the hydrogen as green, it is not certain that other applications will fall under the same requirements. [63] This could be a barrier for the decarbonization of the hard-to-abate sectors that needs to be addressed.

Energinet published in 2019 a paper in relation to REDII on challenges and possibilities that PtX facilities face when seeking to certifying the end product as green, with the purpose of forming a basis for dialogue when discussing regulation and barriers on a national governing level. The paper states that tariffs can be a significant factor in the profitability of an electrofuel facility, exemplified with a methanol production from 20MW electrolysis, and a connection to the distribution net. Further the paper states that electricity to a large-scale electrolysis will be taxed in Denmark. The taxes and tariffs that must be paid are:

- PSO tariff
- Process electricity tax at 0,4 øre/kWh
- Transmission net tariff
- System tariff
- Distribution tariff

Since the PSO tariff is going to be removed by the year 2022, this element will not be included further in this project as it focuses on a case for 2025. An electrolysis can be regarded as process and will therefore only pay process electricity tax. Further it is assumed that the connection to the electrolysis in the case of this project is directly to the transmission grid and therefore the distribution tariff should not be paid either. Was this not the case the facility would be subject to significantly higher cost of accessing electricity.

6.2.2 European Transmission System regulation

The European Union makes cross-border regulation with the purpose of efficient management of the electricity grid, and a fair distribution of cost. Some of the regulation that are relevant to this project is described in this section.

According to the guideline on transmission system operation article 9, the cost of operating and maintaining the transmission grid that by the relevant regulating authority are *"… assessed as reasonable, efficient and proportionate shall be recovered through network tariffs or other appropriate mechanisms."* [65]. This mean that in Denmark, Forsyningstilsynet as the authority assess and approve the tariffs charged by Energinet. Further it means that Energinet is allowed to charge a tariff that cover the cost of the electricity system but nothing more, thereby "rest in itself", this method of charging is also called a cost-plus framework [66]. The use of a cost-plus framework is common in danish utility services.

According to Directive (EU) 2019/943 about the inner market for electricity that, in order to create equal terms for all participants in the market, net tariffs must be used in a way that does create barriers for participating of flexible electricity consumption, or improvements in the efficient use of electricity. Further, according to article 19, tariff methods must happen in a way that incentivizes efficiency, market integration, security of supply, and support efficient investments. This must happen to support research and development activities, and ease innovation in the interest of the consumer within areas like digitalization, and most important in this context, flexibility services. [67]

As an amendment to Directive (EU) 2019/943 the Directive (EU) 2019/944 on common rules for the electricity it is stated that all member states are urged to incentivize investments in flexible energy including storage. It also states that the *"Member states shall ensure transmission system operators … treat market participants engaged in the aggregation of demand response in a non-discriminatory manner alongside producers on the basis of their technical capabilities".* Most relevant to this project the directive states that active clients in the energy market is expected to be charged cost reflective. It is expected that the member states enable the consumers to be supplied with direct lines that are not introducing a disproportionate burden, administrative or cost related. [68]

6.2.3 The electricity utility act

According to §73 in the Danish electricity utility act, tariffing must happen based on reasonable, objective, non-discriminating, and true cost criteria. The term true cost is defined as the cost a consumer category give rise to for the electricity grid. Further, simplicity and transparency are set as a criterion for the tariffing, and it is a criterion that the model can be implemented in reality.

§73 para. 2 states that Forsyningstilsynet can approve methods for certain consumer categories as part of collective electricity supply companies' method development, and that Forsyningstilsynet can set criteria for the approval of these methods. This paragraph allows Energinet to offer optional products with differentiated tariffs in return for a service.

This project interprets the electricity utility act in a strict manner, this means that the criteria of true cost that a consumer category gives rise to is for the electricity grid is not complied with as it is today because of the flat tariff structure further described in section 7.1.

6.3 Landing zones

This section describe landing zones as a regulatory remedy Energinet could utilize to affect placements of electrolyzers in the future.

The concept of landing zones is still being specified, and definitions are therefore not final. But one definition done by Energinet describe it as a defined geographical area that is located upstream of a large renewable electricity production unit, like an offshore wind turbine park. The zone is further described as an area with a large landing capacity and an area that can act as a buffer between the electricity production and the electricity grid. Within the landing zone facilities that can act as sector coupling units will be placed, and price-flexible and interruptible electricity consumption can take place. [39]. The purpose of a strategic placement of these landing zones is to save some of the grid upgrade costs that renewable electricity production will create. A possible placement of a landing zone is near Esbjerg where the CIP project is planned to be built [1].

According to the law on electricity supply §73 *"… price differentiation based on geographic location is only permitted in special instances".* [37]. According to the climate-agreement for energy and industry by the government, the partners agree to change the legislation, to make it facilitate price signals geographic differentiated tariffs. [69].

To incentivize sector coupling technologies and their strategic placement, landing zones could be used as a remedy where the tariff is lower within the zone and would not change the tariff level for consumers outside the landing zone.

Figure 5 Examples of placements of Landing zones (indfødningszone) [1]

7.0 Analysis on tariffs

The following section will identify how the current danish transmission tariffs are structured and seek to find a correlation between cost elements of income, expenses, and tariff pricing at Energinet. Later in the analysis the new proposed product "limited access" from Energinet is described and an alternative to this product is presented.

7.1 Current Danish transmission tariffs

The purpose of the following section is to examine the current tariff structure and the principles behind electricity tariffs on the transmission grid.

7.1.1 Tariffs to Energinet

To finance, maintain and operate the main electricity grid a small tariff is paid for every kWh is produced and a larger tariff is paid by the costumer. The tariffs are set by Energinet, charged by the net company, and is monitored by The Danish Utility Regulator (DUR) after paragraphs 69-73 in the electricity utility act. It is stated that the pricing must happen on:

> *"Reasonable, objective and non-discriminatory criteria for what costs the individual buyer category give rise to"* [37]

7.1.2 Economic breakdown of tariffs

Definition of what the tariff elements cover are described in Energinets note on principles of the electricity market [70]. The tariffs on the transmission grid that is paid to Energinet consists of three different elements:

- Transmission net tariff
    - This element covers the cost of operation and maintenance of the main electricity grid (132/150 and 400 - kV net) and operation and maintenance of the international interconnectors.
- System tariff
    - This element covers cost for security of supply and the quality of the electricity, which includes reserve capacity, system operation and expenses for DataHub
- Balance tariff
    - The cost of system services and handling of the balance market is covered by this element

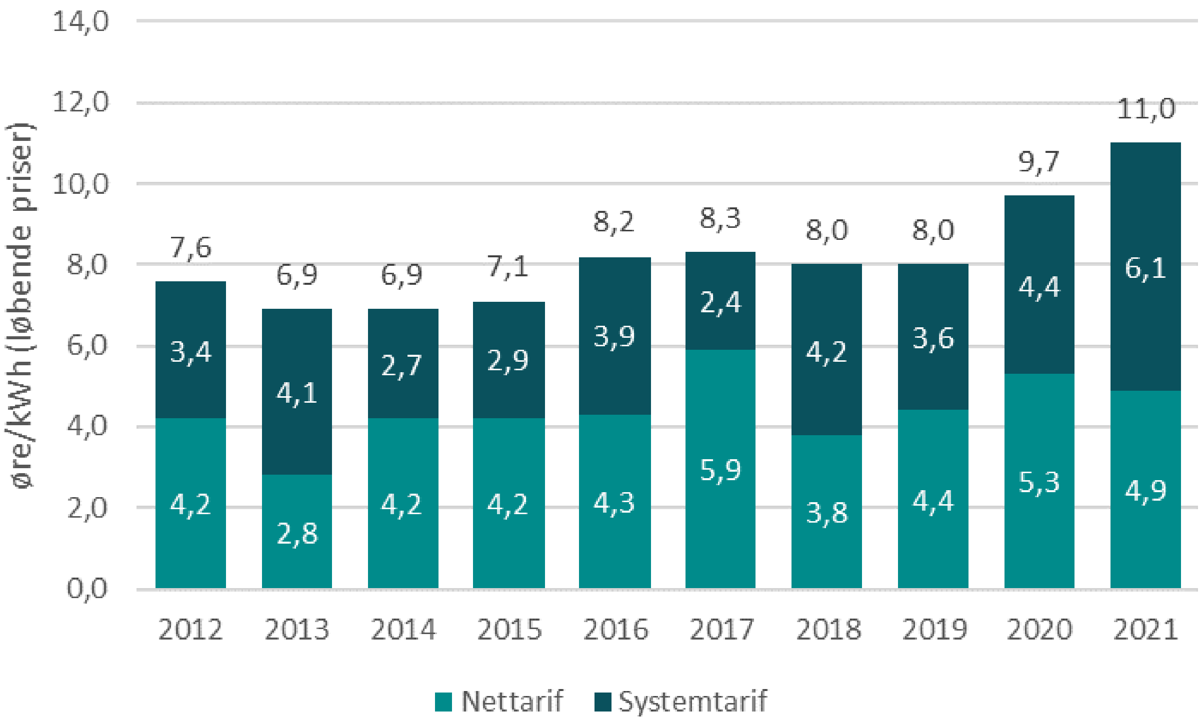


Figure 6: Historical system and net tariffs. Reference: [2]

One of the main tasks of Energinet is to operate and maintain the electricity grid at the lowest cost possible, but due to rising complexity of the electricity system from implementation of renewable production, larger transmission need, and growing electricity consumption, the tariff has been rising which is exemplified in figure 6.

The rates for the transmission, system, and balance tariffs in the year 2021 are summarized in table 2:

Transmission net tariff	System tariff	Balance tariff for consumption	Total tariff for consumer
4,9 øre/kWh	6,1 øre/kWh	0,229 øre/kWh	11,229 øre/kWh

Table 2 Transmission tariffs for consumption on the transmission grid

The yearly expenses for operation and maintenance in Denmark accumulates to 5.0 billion DKK, and this cost is expected to grow over the coming years. One of the consequences for the electricity grid when working towards the national decarbonization goals is more fluctuation in the electricity production as production is shifted from centralized thermal production to decentralized renewable based production. This shift result in longer distances between production and consumption, and therefore growing cost of expansion of the grid. The added complexity with the fluctuating production and electrification of new parts of the energy system will lead to a need for a new tariff structure that leads to a better utilization of the electricity grid and encourages appropriate consumer activity to keep a high security of supply. [71]. According to the electricity supply act it is legal to make price differentiation in consideration of efficient utilization and security of supply [28]. Tariffs on the transmission grid are not differentiated in any way, this result in a lack of price incentivizing signals and is not in accordance with either the EU directive 2019/944 or the danish electricity utility act, further described in section 6.0 because it does not incentivize flexibility services supplied by the market and it does not reflect the cost of what consumer categories give rise to.

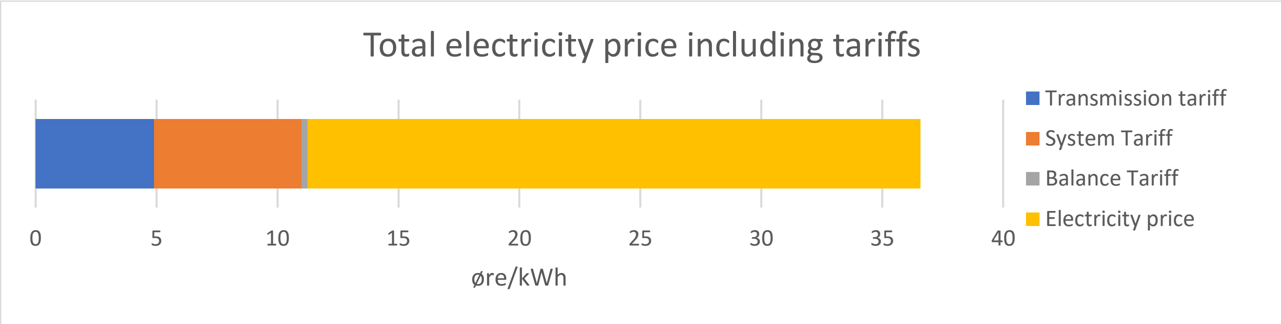
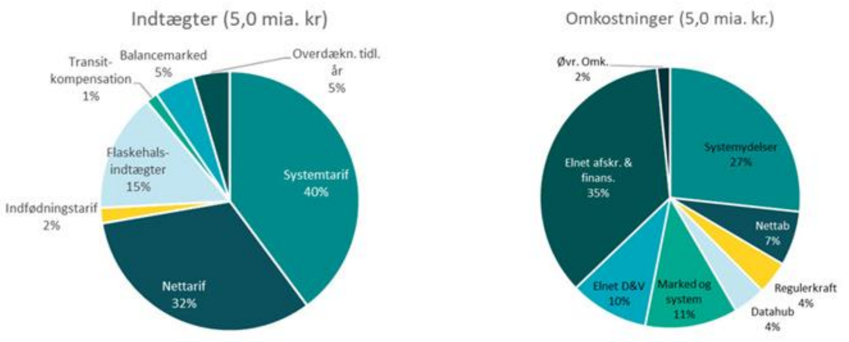


Figure 7 Total electricity price including tariffs electricity price used in this project at 25,35 øre/kWh.

7.2 Correlation between cost elements and tariff rates

This section will seek to find a correlation between cost elements in Energinets expenses, income, and the rate of tariffs. This is done to justify the method of appointing a price to the cost element in relation to a PtX facility. Figure 8 shows the expenses and income of tariffs, and the distribution of elements, as it is shown there is a perfect balance between income and expenses, which it should be according to section 6.2.2.



Figur 1: El-indtægter Figur 2: El-omkostninger

Figure 8: Income (Indtægter) and cost (Omkostninger) for the main danish electricity grid, operated by Energinet. Reference: [2]

In appendix 1, the calculations behind the following 2 tables are made on the basis of figure 8 and the basic electricity projection [53].

Income element	Percentage of income	Calculated income in mill. DKK	Øre/Kwh	Comparison with Energinets tariffs
System tariff	40	2000	6,0	6,1
Transmission net tariff	32	1600	4,8	4,9
Feed in tariff	2	100	0,3	0,3
Bottleneck income	15	750	2,3	
Transit compensation	1	50	0,2	
Balance market	5	250	0,8	0,22
Coverage of previous years	5	250	0,8	
Total	100	5000	15,2	11,5
Total with only consumer tariffs			11,9	11,5

Table 3 Basic cost calculation of income elements in Energinets tariffs and their relation to tariff level. Reference, Energinet, 2021, energinet 2020.

Table 3 shows a correlation between the calculated tariff element and the tariff Energinet charges based on the cost element. According to appendix 1, the percentile difference between the tariff rates from energinet and the calculated rates are 3% and is assessed to be a larger correlation than that of chance, section 5.4. This validates the method of causal analysis on the cost element because of the probabilistic correlation to the income element.

Cost element	Percentage of cost	Calculated cost in mill. DKK	Øre/kWh
System services	27	1350	4,1
Grid losses	7	350	1,1
Regulating power	4	200	0,6
DataHub	4	200	0,6
Market and system	11	550	1,7
Electricity grid operation and maintenance	10	500	1,5
Electricity grid depreciation	35	1750	5,3
Others	2	100	0,3

Table 4 Distribution of Energinets costs in the year 2021

This probabilistic causation is used in section 7.3.2 to estimate what tariff rate a PTX facility will give rise to within each cost element. Further, the same method is applied in table 4, where the cost of each cost element is calculated and translated into a cost per unit power. These cost elements are further assessed in section 7.3.2 and table 4 can be seen as a reference.

7.3 Future possibilities for tariffing

The existing tariff structure is likely to be supplemented by a voluntary product from Energinet that allows for a reduced tariff under certain criteria. This product has been reported to Forsyningstilsynet and have been under review for more than a year [30]. According to the choice awareness theory, section 4.1, society benefits from having several options to choose from. To accommodate the lack of more than one choice, the following section provides a new suggested rate of tariff.

7.3.1 Limited net access

Traditionally network access has been granted at all times to the consumer, and no cap on maximum electricity consumption has been present as long as the maximum effect withdrawn from the net has been within the allocated capacity. Security of supply has been a subject with a lot of political and technical focus through the expansion of the Danish electricity grid, and with great success. This large focus has resulted in a strategy where the transmission lines in larger supply areas are backed up by at least one extra line, that in some cases allows for scheduled and non-scheduled fallouts simultaneously without disadvantages for the consumer. These back up lines are unused most of the time. [72].

To solve several challenges like utilizing the electricity grid better, accelerate the green transition, and to better accommodate the electricity utility act, Energinet is wants to implement a new voluntary product to consumers connected to the transmission grid [73]. Costumers will have limited access to the electricity grid, meaning that in a situation where consumption limitation is necessary to maintain security of supply, the consumer will either be obliged to operate at a certain capacity or completely be shut off. [74]. This will add value to the electricity grid as it allows the grid to utilize the existing grid at a higher rate at no marginal cost. For the consumer with a large and flexible electricity demand, it allows for a product where the tariff is lower in exchange for being interruptible. The method review have been reported to Forsyningstilsynet and is currently being processed.

The DSO’s have had the possibility to offer a similar product for electrical boilers in the decentralized heating and power plants, but the key difference between the two models is that the DSOs are allowed to exempt from the connection tariff, where Energinet will give a discount on the transmission net tariff. [72]

Energinet have assessed “Limited access” in relation to the criteria about cost-relatedness and finds that the consumer will not give rise to added cost in expansion of the electricity grid, and that cost of interest and depreciation accumulates to a possible reduction in tariff which result in a new transmission net tariff of 2,1 øre/kWh, and the system tariff will not change [72]. If this rate is chosen as the new total tariff for the consumer will be as follows:

$$Systemtariff + Transmission\ net\ tariff + balance\ tariff$$
$$= 4.4\ \text{øre/kWh} + 2.1\ øre/kWh + 0{,}187\ øre/kWh = \mathbf{6{,}687 øre/kWh}$$

It should be noted that since the method for calculating the reduced tariff states that the consumer must contribute to the cost of other elements than the interest and depreciation, therefore the rate of the tariff will vary from year to year, and the calculated tariff in this example is based on 2020 rates.

Energinet has made an impact analysis on the introduction on the new product of limited net access and assessed whether or not this introduction will improve the model for tariffing. The impact analysis assess how introduction of the new product will affect the accommodation with the electricity utility act in accordance with the principles of fairness, true cost, and non-discrimination. It is underlined that the new rate of transmission tariff is not necessarily the ideal rate, but rather an improvement and an addition to the existing model. Further it is concluded that on all criteria introduction of the new product will improve the existing model. [73]

According to Energinet the expenses covered by the system tariff is considered a common cost, and therefore no argument is found to offer a reduced system tariff [72]. The thesis in this project is that this makes for a less true cost compared to a rate that reflects the true cost of all cost elements in both tariffs, which is what the following analysis will investigate.

It should be noted that Energinet also has reported a method review for a new product to Forsyninstilsynet called "temporary limited net access", but as this product is only a temporary solution, until full net access for the consumer is available, this product is not assessed to be a solution able to fulfill the requirements of a PTX facility and serve as a solution with a viable reduced tariff [75].

7.3.2 New proposed tariff rate for incentivizing flexible consumption

According to the electricity supply act, the pricing of tariffs must happen on "Reasonable, objective and non-discriminatory criteria for what costs the individual buyer category give rise to" [37]. The current tariffs charged by Energinet are socialized on all consumers, which means some consumers give rise to far more cost for the electricity grid than what they contribute via their tariffs, and some pay more than what they give rise to. In some instances, like PtX, the difference they pay versus the cost they give rise to can be significant and create inappropriate barriers for the investors. [38].

The purpose of this analysis is to find a tariff level that will reflect the true cost to the electricity grid of installing and operating an electrolysis with the purpose of producing electrofuels. This new tariff rate should be applicable to a new consumer category called "Flexible PtX". The approach in the analysis will be to analyze the cost elements from figure 8 of the tariffs and estimate the cost a PtX facility will give rise to in the grid.

System Services

Energinet has the overall responsibility for a series of tasks with the purpose of maintain a stable electricity grid, and thereby security of supply. These are called system services and are necessary to the grid both under normal operation and in recovery after failure, they are charged under the system tariff. The largest part of the cost of system services is frequency balancing [76].

The Danish Utility Regulator has published a report in 2018 with a summary of the expenses to system services, including reserve capacity, electricity quality and security of supply Energinet have had in the period from 2013 to 2017 [77]. The costs are summarized in table 5.

2013	2014	2015	2016	2017	Average
788	844	705	861	598	759

Table 5 Total annual cost of system services in million DKK. Reference: (Forsyningstilsynet, 2018)

According to table 4, the systems services in year 2021 was calculated to 1350 million DKK, and it cannot be explained why this very large difference from the average value in table 5 occurs. One explanation could be that the difference is due to administration and development resources in Energinet. Whether or not a PtX facility give rise to added cost for system services depend on factors like technical capabilities like ramping configurations, the geographical placement, and the purchasing strategy of Energinet. [26]

According to Energinet, and an ongoing revision of the model for charging system tariffs, the cost of system services is projected to rise in the coming years. More than 90% of the cost of system services is related to frequency balancing. [76].

It is estimated that a PtX facility can benefit the electricity grid without giving rise to added cost themselves. Therefore, a PtX facility can lower the cost for Energinet to system services by providing frequency stability abilities and make the cost for this consumer category negative. An estimate of this negative cost could show that a PtX facility lowers the cost of system services corresponding to 10% of the maximum capacity in Denmark contributing approximately with -100 million DKK [26], which according to the method translates in to -0,3 øre/kWh. Energinet backs the theses that a strategically well placed PtX facility can contribute to saved grid services [78].

Other sources do not agree to which degree electrolyzers will be able to deliver balancing services. Depending on the electrolyzer, the ramping time vary a lot, and is not able to provide the same regulation ability in ramp-up as in ramp-down situations. Alkaline electrolyzers are not able to react fast enough to participate in frequency reserves. But is a SOEC electrolyzer chosen, it is estimated that it can participate in frequency balancing on all levels [79]. While this might be the case with traditional alkaline electrolyzers, it might be an issue that can be overcome. More recently it has been shown that if the electrolyzer is equipped with additional equipment that allow the electrolyzer to respond to frequency deviation, an electrolyzer will be able to deliver more efficient frequency services than conventional generators [80].

Under assumption that it is possible to alter the electrolyzer in a fashion that allows it to participate in frequency balancing, Lindboe' assessment of the rate of -0,3 øre/kWh is kept, but it is simultaneously stated that this value might be optimistic, and further analysis including modelling hereof need to verify the claim.

Grid Losses

A PtX facility is operational when the electricity price is low, and it will be connected to the transmission grid. One argument for placing the PTX facility in a landing zone is that it then will be able to reduce the strain on the transmission grid further down the grid. This combined with the assumption that the placement is in a landing zone with a connection directly in a DC/AC transformer connected to the cable from an offshore wind turbine park, argues for very low grid losses.

Under the assumption that the electrolysis is operating at 4500 full load hours and a grid loss of 2% and the electricity price from section 5.3.1 of 34,04 EUR/MWh, a PTX facility like the Esbjerg Case will give rise to 0,1 øre/kWh, and the tariff pricing should be set at this rate to follow the criteria of true cost.

Regulating power

It is assumed that this cost element is covering energy payments in the regulating power marked, and this cost is covered by those responsible for the balance. A well-integrated flexible consumer will not give rise to an added need for regulating power at all. The flexible consumer will be able to deliver regulating power, and thereby give rise to a negative cost, depending on the strategy of operation. For the purpose of this analysis the consumer category cost is set to zero. [26].

DataHub

All danish consumer information is collected and managed in the DataHub. The data in the hub is collected through measuring points like a household electricity meter, and it is the amount of measuring points that determines the cost of operation of the DataHub, not the capacity of the consumer or the yearly electricity consumption. Besides handling data about consumers like change in supplier of electricity and households moving, the DataHub is a contributing factor in keeping the balance between consumption and production of electricity. In current regulation, the cost of operating the DataHub is covered by the system tariff, but this could change in the future, and be covered by a subscription service, making the model more in line with the criteria on true cost [30].

As there are 3,3 million consumers to split the cost of 200 million DKK, a cost of 60,6 kr./year/measuring point is negligible for a consumer like a PtX operator. In this analysis the cost is set to zero. [2]

Market and system

This cost element consists of general work with market and system development, and it is assumed that the cost of 550 million DKK must be socialized on all consumers, and that a PtX facility and other consumer categories will not give rise to an added cost of this element. Without further proof hereof, it cannot be argued that PtX facilities should give rise to more or less cost than other consumer categories. [26] The cost of the element will be included in the cost element “others”.

Electricity grid operation and maintenance & Electricity grid depreciation

According to the “Reinvestment, expansion, and redevelopment plan” Energinet published in 2018, the cost of grid reinforcements, redevelopment, and reinvestments in the period from 2019-2028 accumulates to a maximum of 45 billion DKK. As shown on figure 9, by far the largest proportion of this cost is caused by grid reinforcements. The plan states that the cause of this is expansion of the trading capacity to neighboring countries, and grid connection of the upcoming wind turbine parks. [3].

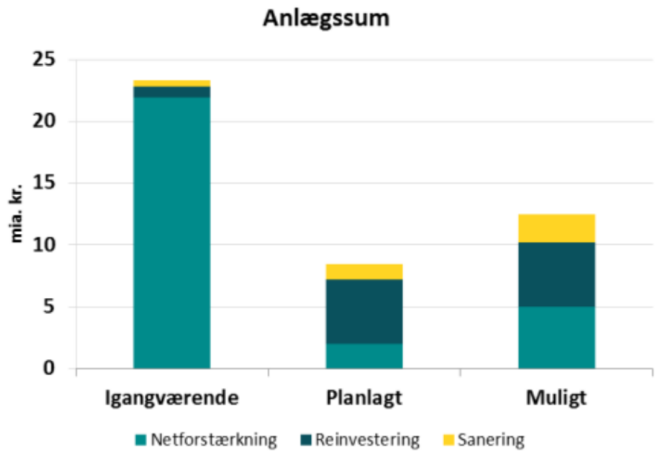


Figure 9: Accumulated investments in the danish electricity grid, current (Igangværende), Planned (Planlagt), Possible (Muligt). [3]

According to the calculation in appendix 1 hereabout, where the following assumptions are made; lifetime of components: 40 years, an interest rate of 4%, the yearly expense to this cost element accumulates to 2,3 billion DKK. As the dominating cost of this element is investments in interconnectors, it is assumed that the cost will in large parts be covered by bottleneck income. Bottleneck income is the income from operating the interconnector on the market, and in 2019 the income hereof accumulated to approximately 600 million DKK [81]

According to multiple references a well-placed PtX facility can give rise to none or even negative cost need for grid reinforcements [39] [26] [78]. Even the method review for limited net access back this statement [72]. A consumer that contributes to a lower demand for interconnectors cannot be asked to contribute to the payment hereof in order to fulfill the definition of the true cost criteria of the electricity utility act, clarified in this project with a strict definition in section 6.2.3. The consumer category should pay no or very low tariffs for this element. The portion of this element is set to 0 øre/kWh in this analysis, but further analysis would be appropriate to further qualify what cost the consumer category give rise to, which might show a negative price of this cost element.

Others

This analysis is a simple causal analysis, and in a more in-depth analysis it might be found that the main proportion of the cost of the electricity system is attributable to the consumer categories that give rise to them. After such an in-depth analysis, a cost of 400-500 million would be found that cannot be attributed to a consumer category. Combined with the cost of the cost element market and system, a cost of 1 billion DKK is to be socialized between all consumer categories. [26]. In 2021, 1 billion DKK corresponds to a 3 øre/kWh tariff.

Summery

This causal analysis shows that neither the existing tariff rate nor the rate in “limited access” seems to reflect the true cost of what a PtX facility connected to the transmission grid give rise to.

Pricing of the cost elements are summarized in table 6, and a tariff of the flexible demand rate is found:

System services	Grid losses	Regulating power	Datahub	Electricity grid operation and maintenance & Electricity grid depreciation	Others	**Total tariff**
-0,3 øre/kWh	0,1 øre/kWh	0 øre/kWh	0 øre/kWh	0 øre/kWh	3 øre/kWh	**2,8 øre/kWh**

Table 6 Summery of the new suggested tariff

For the tariff rate for PTX-facilities to reflect the true cost of what they will give rise to some assumptions are made, and these must be complied with for the benefits to the transmission grid to be valid. The most important assumption is that the location of the facility is strategically well placed in relation to the transmission grid. Therefore, it is suggested that in order for the facility to obtain a tariff rate of 2,8 øre/kWh the placement must be in a landing zone like the ones suggested in [1]. Further it should be a requirement that the electrolyzer is fitted with equipment that allows it to participate in frequency balancing. This also implies that the requirement of the facility to be an interruptible costumer must be met.

7.4 Sub conclusion

In section 7.2 it is found that a causal analysis on the cost elements of tariffs is justified because of the correlation between the cost element and the income element in the tariff charged. The new product "limited access" is found to not assign a suiting tariff rate as it will not reflect the true cost of what a PtX facility give rise to. Further it is found that the new product does not allow for a reduced system tariff, but only a reduced transmissions net tariff which is not fair to PtX facilities, as the main cost of the system services are caused by frequency balancing, and PtX facilities can give rise to negative cost related to this element.

It can be concluded that the current tariff structure is not in accordance with the EU regulation 2019/943, because the flat tariff structure does not create incentives for flexible demand. By the causal analysis, a tariff of 2,8 øre/kWh is found to better reflect the true cost of what a well-placed PtX facility will give rise to under the criteria set in section 7.3.2.

Tariff rates found in this analysis that will be used in further analysis on Levelized Cost of Energy and abatement cost are summarized in table 7:

Current level	Limited access	Flexible consumption
11,229 øre/kWh	6,687 øre/kWh	2,8 øre/kWh
15,07 EUR/MWh	8,98 EUR/MWh	3,76 EUR/MWh

Table 7: Summarization of average tariff in chosen models

8.0 Levelized cost of ammonia in Esbjerg

This analysis will analyze the effects of the existing and new tariffs will have on the economy of the Esbjerg case, where a 1 GW electrolysis will be used to produce ammonia. The calculations are done as described in the method section and can be found in appendix 1. The investors plan to begin operation of the facility in the year 2025, and therefore the calculations in this analysis will be done for this year. As the technology catalogue only states values for 2020 and 2030, an average between these years was used.

To assess the possible abatable amount of CO_2, an emission factor must be found for the fossil ammonia production. As this is an influential factor to the calculations, to do so an average value of several references was used, summarized in the following table, and leading to a value of 1,64 ton of CO_2/ton of ammonia.

Reference	Emission factor	Note on plant	Input of plant
IPCC [82]	1,7	Modern plant	Natural Gas
Topsøe et. Al. [58]	1,6	Modern plant	Natural Gas
Topsøe et. Al. [58]	2	Existing plant	Natural Gas
Argus [83]	1,2-1,6	Current technology	Natural Gas
Stuttgart University [84]	1,56	Best available technology	Natural Gas
IEA [85]	1,6	Average plant	Natural Gas
IEA Bioenergy [86]	1,15-2,1	BAT – Average	Natural Gas
Average	1,54-1,74 (**1,64**)	-	-

Table 8 Meta study on emission factors for fossil ammonia

8.1 Presentation of results

The price of green ammonia has been estimated including existing tariffs in the base scenario. This is done to exemplify how the economy of the facility would be with no change in tariff level.

System characteristics		System Economics	
Electrolyzer capacity	1000 MW	Tariff rate	15,07 EUR/MWh
Fuel synthesis capacity	549,4 MW	Electricity price	33,8 EUR/MWh
Ammonia output	478.519 ton	Cost of green ammonia	728 EUR/ton
Usable heat output	119,620 MWh	Abatement cost	319 EUR/ton

Table 9 System characteristics and economics, base case yearly output

As it can be seen in table 9, production of green ammonia has a significant abatement cost of 319 EUR/ton. This abatement cost is found to be in line with other findings about abatement cost of hydrogenation processes, qualifying the calculations in this project [87], [88].

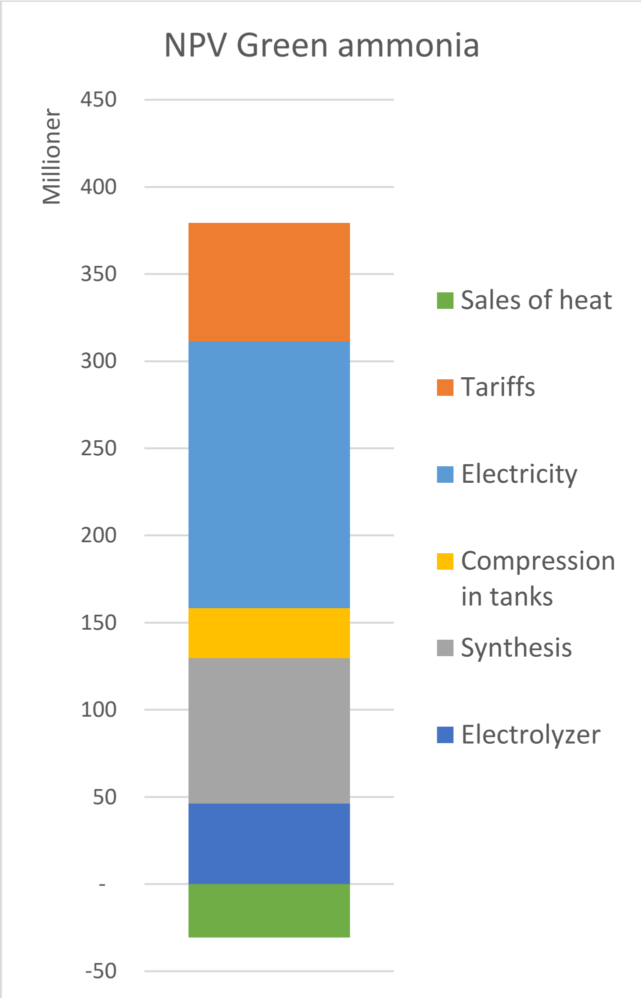


Figure 10 Cost elements in the system. Base case

As it is apparent from figure 10, tariffs amount to a significant amount of the total economy of the PTX-facility. At a total amount of 67,8 million EUR annually, the tariffs account for 19,3% of the total economy of the facility in the base case. This must be seen as a significantly higher proportion of the operation cost than what other consumer categories must pay in tariffs [26].

The facility will be able to produce 478.510 ton of ammonia annually, which under the assumption that all electricity is from renewable sources will abate 790,612 tons of CO_2. This will require 4,5 TWh of renewable electricity and produce 947.620 MWh of excess heat that can be utilized in the district heating system under the assumption that the district heating system has the required demand.

8.2 Sensitivity to tariffs

This section will present the calculations done in appendix 1 and consists of a sensitivity analysis with the tariff rates found previously as the only changing factors compared to the base case.

Cost\Tariff rate	Base case	Limited access	Flexible consumption	0-tariff case
Tariff rate	15,07 EUR/MWh	8,98 EUR/MWh	3,76 EUR/MWh	-
Cost of ammonia	728 EUR/ton	671 EUR/ton	623 EUR/ton	588 EUR/ton
Percent diff./ton ammo	-	-7,2%	-16,8%	-19,2%
CO_2 Abatement cost	319 EUR/ton	284 EUR/ton	255 EUR/ton	233 EUR/ton

Figure 11 Summary of effects on cost of fuel and abatement cost

As it is apparent from table 11, in none of the cases, the cost of ammonia reaches a level that is competitive with fossil ammonia. But in the case of the flexible consumption rate the abatement cost is 20% lower than in the base case. This price difference is found to be significant, and the argument could be made that when governing bodies will decide which technologies to subsidize, renewable ammonia production will be treated unfairly because the abatement cost in the base case does not reflect what cost the facility gives rise to for the transmission grid.

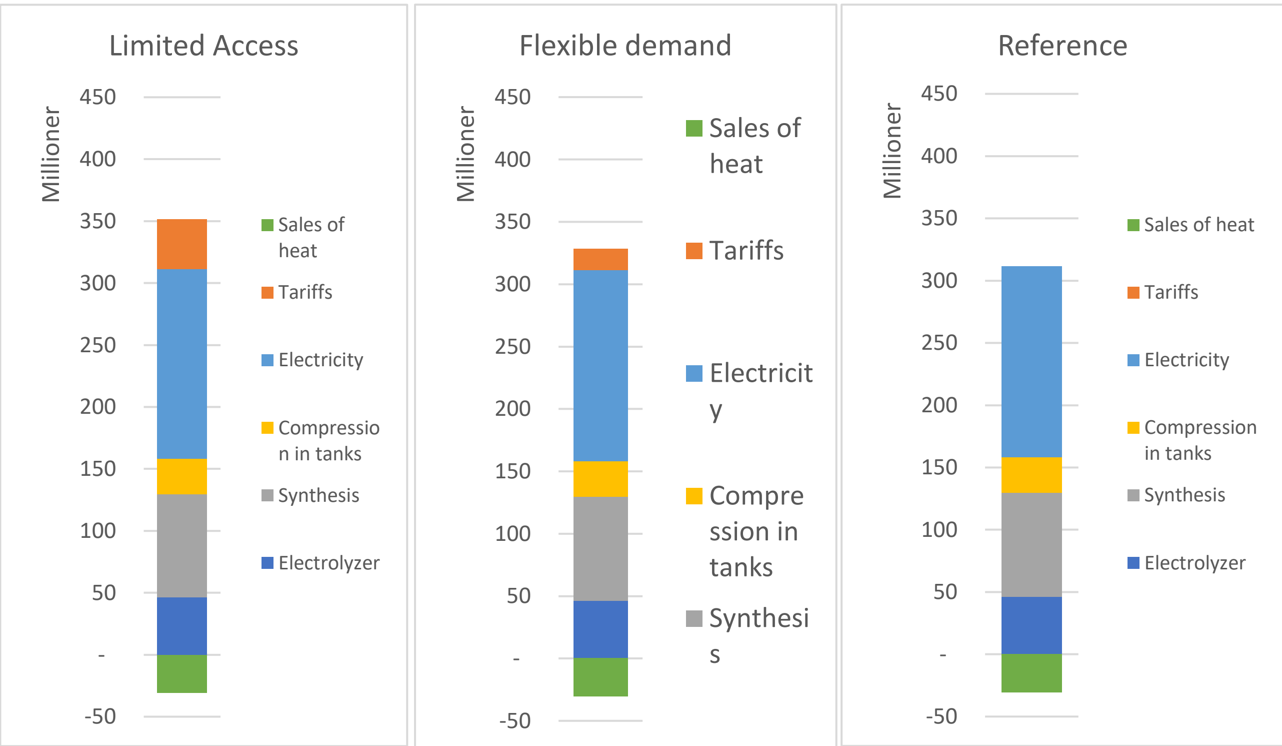


Figure 12 Cost elements represented in the 3 sensitivity scenarios

8.3 Sub conclusion

It can be concluded that it was possible to calculate the LCOE and the abatement cost of the renewable ammonia production and the sensitivity to tariffs. The abatement cost in all cases is found to be significantly above zero and the abatement cost was found to be very sensitive to tariffs. This analysis allowed the project to answer the third sub research question in section 2.0.

9.0 Multi criteria analysis

In this analysis the previously processed tariffing rates are scored in table 10, and the scores are expanded upon after. This will allow the project to answer the fourth research question in section 2.0, and to accommodate the choice awareness theories statement that on central parameters the solutions should be compared to raise the choice awareness, section 4.1.

Rates / Criteria	True cost	Reasonable	Non-discriminating	Objective	LCOE/ammo (EUR/ton)	Abatement cost (EUR/ton
Existing rate	1	1	3	1	728	319
Limited access	2	1	2	2	671	284
Flexible consumption	3	2	1	3	623	255

Table 10 Comparison and scoring of tariff rates

It should be noted that as the project is aimed at PTX facilities the scoring has been done with those in mind. There could be arguments for why the models would score otherwise if the analysis were done with other consumer categories in mind. It is found in section 7.3.2 that the existing rate of tariffs does not reflect the true cost of what a PTX facility give rise to. Because the tariff rate is the same for all consumers, the existing rate gets appointed the lowest score. The limited access rate allows for a lowered transmission tariff, which does reflect the true cost more than the existing rate. But as the system tariff is still unchanged, and section 7.3.2 argues that this should not be the case, the rate in the limited access model gets appointed the score 2. It is found in section 7.3.2 that the flexible consumption rate reflects the cost a PtX facility gives rise to and is therefore appointed the maximum score of 3. Both the existing rate and the rate proposed in the limited access product gets appointed the score 1 in the criteria of reasonable as they are both found to favor some consumers at the expense of others. The new proposed rate does not accommodate a higher cost for consumers that give rise to added cost on the grid but is assessed to be a more reasonable solution than the two others, therefore the differentiation in scores. As the existing rate is a flat tariff that is socialized without discrimination this rate scores the highest, whereas the two others discriminate in that they have differentiated tariffs. Limited access targets large consumers, whereas the new proposed rate only target PTX facilities. The existing model is not very transparent, but the model limited net access is found to be better in the sense that descriptions of the method are readily available, but the calculations behind the proposed rates are not very transparent. As the new proposed model was done as objective as possible, and with very transparent methods that have been validated by external sources, this model is appointed the maximum score.

10.0 Discussion

The discussion of this report will handle some of the findings of the report and put them in to context. Further it will discuss the topic in general and later the regulatory framework of the technology in general, and the theory and methods used in the analysis.

10.1 Green ammonia as a decarbonization mechanism

In a report on the pathways to reach the reduction targets set in the 70-% goal and the 1,5-degree scenario of the IPCC the Danish council on climate mitigation suggested a carbon tax of 1500 DKK/ton CO_2. [89]. The calculations of abatement cost in this project finds the abatement cost of green ammonia in Esbjerg in 2025 to be between 255 and 319 EUR which translates in to between 1900 and 2377 DKK. Which means that even with a tariff that reflects the true cost of what the facility will give rise to, the green ammonia will still not be competitive with the fossil alternative, even with the carbon penalty that the council of climate change suggest. This argues for green ammonia as an inefficient means of decarbonization, and that other measures should be investigated before green ammonia. Blue hydrogen could be a more cost-efficient way of reducing emissions than green hydrogen in order to reach climate goals in 2030 [18]. The argument against this is the need for development to reach long term cost reductions of the technology. As the development of offshore wind turbines in the last 30 years have been a business adventure with great benefits for Denmark, the same could be the possibility for PTX. Denmark has optimal conditions for development of the technology with cheap renewable electricity, geographic location close to both Germany and Sweden, both with opportunities for export, and a strong research institutional community. Germany has made the statement that they will not be able to produce all the green hydrogen they project to consume in the future and are therefore in need of import [90]. If one takes the view that it is very important to comply with the current goals, the argument against green ammonia might be chosen. But one could also choose to follow another discourse and argue that the long-term cost-effective reductions are the most reasonable and long-term cost-effective strategy for solving the climate crisis. Following this argument there is a need for investments in the technology now that will facilitate the desired cost reductions in the future. According to Lindboe, the cost of fossil ammonia is expected to rise in the future, and the CAPEX of electrolysis is expected to decrease significantly, resulting in an even lower abatement cost of ammonia and other electrofuels that further strengthens the argument of electrofuels in general. [26]

10.2 Price discrimination in tariffs

There is a need for subsidization of the technology for investments to happen. There is simultaneously a need for a review of the current tariff structure. One could argue that if a reduced tariff for PTX facilities is allowed, that it would be unfair price discrimination, section 4.1, and with good reason. But as the marked has not been able to account for climate change, a market failure is present. As found in section it would be possible to reduce the transmission tariffs for an ammonia facility and achieve a 16,8% production cost reduction with the added benefit of the new proposed model to comply better with relevant regulation than what the current structure does. As there is a common quantity between the green transition and true cost, figure 1., the argument is made here that as a first step in a process of making tariffs on the transmission grid reflect true cost for every consumer category, PTX facilities would be an appropriate first consumer category to revise. The new proposed tariff in this project is not seen as a subsidization as it reflects the true cost of the consumer category, but rather as a remedy to utilize the common quantity of figure 1. Energinet having a product available for only one consumer category is obviously not fair and can be seen as price discrimination. Other consumer categories might have the same disadvantages that a unproportionally large amount of the operational cost is tariffs, and an argument could be made that this price discrimination should also be addressed. The argument against it is that it takes a lot of resources and time to reform the tariff system, that traditionally had a flat rate as it was the only possible way to charge for consumption. Due to technological advancement like computers and smart electricity meters, it has become easier to differentiate tariffs, but the reform of the system will still take time.

10.3 Choice awareness theory

As the theory states, the more options decision makers have to choose from, the larger the benefit for society. Further, the more detailed the proposals, the larger the chances are that the proposal will be taken into consideration. These two considerations will contribute to a more efficient and fair transition of the energy system, but it will also put a burden on the civil services that must prepare and present the options available. As the theory originated at the university, an actor with interests in pushing their agenda might argue that this burden will be an insurmountable and inappropriate barrier and that it is idealistic to enlighten about all options, revealing their effort to highlight choice eliminating mechanisms. According to Energinet a criterion set for a new tariff model to be perfectly ideal, will hinder improvements to be implemented, stagnate the development and thereby keep the system locked in the same model that already exist [73]. The danger is that being aware of too few options will lead to solutions that are not cost effective, which will be a much larger cost for society than to pay the extra cost of enlightening the community. In the case of transmission tariffs, the argument can be made that there currently exists price discrimination in the sense that some consumers like a PTX facility, large heat pumps, or households at certain hours of the day pay more than what they give rise to. At the same time, some consumers like industry with a large non-flexible electricity consumption will pay to less than what they give rise to. An investor might argue that the flat tariff rate could be seen as a tax on turnover for the business and that it is unfair as only profit is taxed in Denmark normally. This issue result in barriers for the green transition, that might lead to an inappropriate cost for society, being aware of several options will benefit society.

10.4 Regulation

Several of the principles in the electricity utility act are conflicting. As it is apparent from table 10, the scoring of the different rates in this project reflects this. If the principle of true cost were to be followed strictly, every consumer would pay a different tariff, leading to a monumental administrative burden of calculating the rates, and the system would not be simple. As a mid-way between a flat tariff and a strictly true cost tariff, consumer categories can be seen as a good solution. But this leads to issues on differentiated locations of facilities, as the regulation currently prohibits geographic differentiation of tariffs in the transmission grid, energinet has no remedy for incentivizing strategically placement of consumers, which might be part of the reason for why the model limited access does not give a reduced system tariff, but only a reduced transmission tariff. As previously mentioned, the agreement on industry and energy states that this prohibition will be lifted, which will further strengthen energinet in a cost-efficient management of the transmission grid. As there is still limited experience with large scale electrolyzers in Denmark, it is difficult to assess how flexible they will be. This factor might play an important role in the future tariffing pricing, as they might not be flexible enough to provide frequency balancing, resulting in a higher system tariff than what is proposed in this project.

It is difficult to assess whether or not the reasons given in this project for why there are currently no differentiation of tariffs in the transmission grid, are choice eliminating mechanisms, or they are valid excuses. The relationship between energinet and Forsyningstilsynet can be criticized for being a barrier for a fast and effective handling of assignments as is the case with the method review of "limited access" that have been processed for more than a year now by Forsyningstilsynet. Currently Energinet reports a new tariff structure to Forsyningstilsynet who review the method, and then ask Energinet to make an impact assessment of the new structure. This leads to an administrative burden and long case processing times. A metaphor for this can be drivers asking the police how fast they are allowed to drive on the road, instead of the police just assigning a speed limit to the road. These are arguments for why the regulatory barrier could be a reason to why there is no differentiated tariffs yet. On the other hand, historically decisions have been made incredible fast on certain topics, and that raises the question of why action have not been taken earlier. No clear answer can be extracted from this project, but it is clear that the current tariff structure is an inappropriate boundary for PTX facilities. This is further underlined by a statement from David Hartz from Energinet that they are limited by European law to charge renewable electricity production a certain tariff. These tariffs are not sufficient to cover the cost of connecting new production facilities, and therefore must this cost be socialized on other costumers. This issue begs the question why renewable electricity production is exempt from paying what they give rise to for the electricity grid when PtX facilities must pay far more than what they give rise to.

11.0 Conclusion

The project assessed the causal effect between cost of the transmission grid and the income elements of the tariffs. The results were used to estimate a new rate of tariff that reflect what cost a PtX facility give rise to. a sensitivity analysis was done to demonstrate the economic consequences of different tariff rates for the planned ammonia plant in Esbjerg.

It can be concluded that PtX facilities will pay an inappropriate tariff to utilize the transmission grid if the current tariff is to be paid, the tariff will constitute 19,5% of the total economy of the facility. It can also be concluded that even with the new product "Limited Access" PtX facilities will pay more than what they give rise to for the transmission grid, under assumption that the facility is located strategically well. This is found to not be in line with the danish electricity utility act on the criteria of true cost, and it is also found not to be in line with EU directives which states that flexible consumption must be incentivized.

The chosen methods of the project served the purpose they were intended to and that they were well fitting to the chosen theoretical framework. The methods and theory made it possible to answer the problem formulation, and a new proposed rate of tariff was found, that reflects the true cost of what a PtX facility give rise to.

It can be concluded that green ammonia from electrolysis can be produced at a price of 728 EUR/ton with the current tariff rate, and at a price of 623 EUR/ton with the new proposed tariff. This result in an abatement cost of 319 and 255 EUR/ton CO_2.

Energinet has only reported one product to Forsyningstilsynet that will allow for differentiated tariffs on the transmission grid. It was found that this is contradictory to what the choice awareness theory states on being enlightened on several options, and that choice eliminating mechanisms was used as excuses for why there is only one option in review.

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