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PTX Project Implementation of Two Projects in Denmark: Takeaways and Insights

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ABSTRACT

This paper investigates the project implementation of e-fuel production in Denmark to compare two projects and execute interviews with project employees, experts within the e-fuel field and authorities both local and national. A SWOT analysis of the interview outcomes was conducted as well as an internal and external factor evaluation. The analyses highlight the internal and external project factors that impact the implementation of these projects in Denmark. The analysis showed that collaboration and engagement of stakeholders, citizens and authorities to a large extent can mitigate hindrances and drive the projects forward in development. Large interest in these projects from all sides of the project implementation and development is a part of this. A threat to the implementation is the uncertain and rigid regulatory framework that involves permitting processes and conditions such as tax reductions. This threat can to a large extent be aided by the collaboration with stakeholders. The regulatory framework is not fit to the novelty of these cases which poses new requirements to the framework. Market readiness and offtake agreements pose obstacles for the projects, which are both external and internal conditions of the projects. The topic of the amount of renewable electricity in the grid is discussed among the interviewees and shows a discrepancy on whether or not this is an issue for the projects. However, it seems to be an issue only for projects that are expected to be in commission before 2028 where the electricity in the grid is not generated by renewable energy only.

Keywords

Power-to-x;
PtX;
SWOT Analysis;
E-fuel;
Project implementation

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1. Introduction

The production of synthetic gasses and e-fuels through electrolysis and utilization of renewable electricity, also known as Power-to-X (PtX), is one of the pathways to decarbonize sectors such as heavy-duty transport [1]–[2] and industries reliant on gas [3]. With the increasing need for energy security along with the reduction of greenhouse gas emissions, PtX is a fundamental technology for reaching a carbon-neutral society [4]. Furthermore, PtX is an enabler of sector coupling, which is the backbone of the EU hydrogen roadmap [5], thus underlining the importance of implementing these 'new' technologies successfully. Experience with other renewable energy projects in the past shows that regulatory frameworks and attention to planning processes are a vital element to a successful implementation [6]–[9] which indicates that this also could be an element to investigate for PtX projects. Several PtX projects on a demonstration level have been announced and completed in Europe and globally [10], [11]. Denmark is one of the countries with the most announced e-fuel projects highlighting Denmark as a pioneering country in technology development and deployment [12]. The readiness and potential

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Abbreviations

CCU	Carbon Capture and Utilization
FEED	Front End Engineering Design
FID	Final Investment Decision
LPG	Liquified Petroleum Gas
PtX	Power-to-X
RFNBO	Renewable Fuels of Non-Biological Origin
RWGS	Reverse Water Gas Shift
SAF	Sustainable Aviation Fuel
SWOT	Strengths, Weaknesses, Opportunities and Threats

of the technology have been investigated [10], however, no attention is drawn to the implementation of GW scale projects, though the need for a hydrogen infrastructure together with these project's development is problematized for the diffusion of PtX [11]. Chehade et al. [10] reviewed 192 demonstration projects with the production of green hydrogen and mentioned the aspect of missing regulation as a barrier. This means that a supportive regulatory framework is pertinent for the further development of these types of projects.

The commercialization of the technology needs a supporting regulatory environment, and it appears to be a main subject for the implementation of large-scale PtX projects [4]. This is also supported by Csedo & Zavarkó [13] who examine power-to-gas with biological methanation as an innovative energy storage technology in Hungary. The paper examines what drives the transformation of the renewable energy sector with a focus on organizational and innovative management. It is pointed out that strict regulations and rigid institutions often lead to less innovative solutions when working with new technologies. Furthermore, a study investigating business models of sector coupling involving green hydrogen stresses that optimal framework conditions are necessary for market formation [14]. A look into the Mexican framework conditions by Rodríguez et al. [15] further suggests that the energy governance is battling several challenges e.g. technological, human and economic nature that in part discourages the hydrogen market, which further suggests that strong policy support is necessary for the transition.

According to Incer-Valverde et al. [16], the political willingness to support the diffusion of hydrogen can be seen through the many national plans and strategies that have been carried out by more than 30 countries on a global scale. Nonetheless, there is still a need for additional policies and regulations to decrease the cost of PtX and thereby ensure implementation [16]. The need for new policies and a dedicated framework is also noted by Skov et al. [17]. This especially relates to the formation of support schemes to reduce cost and uncertainties, and it is framed as one of the most important threats to the development of PtX [17]. Uncertainties due to the cross-sectoral composition of PtX can induce a delay in the implementation due to diverging interests. Understanding these factors that can create hindrances is important for the involved actors. However, analyses of the institutional setting underline that PtX lacks a rounded regulatory framework that is indifferent to end-use [18]. The regulatory environment and incentive structures are also stated as one of the drivers of PtX, which is supported by Skov & Schneider [19].

The change in the Renewable Energy Directive (RED) from 2018 marks the first steps of a PtX framework in the EU with the mention of hydrogen use [20]. This can lead to market formation which is also known as one of the largest weaknesses of the technology [18]. With the adoption of another two delegated acts under RED, the EU sets an important milestone in the creation of a regulatory framework that reduces uncertainties in the PtX projects under development [21].

An aspect related to the implementation of large-scale PtX entities is the lack of experiences with social acceptance and therefore it is difficult to conclude the matter of social acceptance [22]. However, other studies suggest that public perceptions of green ammonia and the technology deployment are overall positive, whereas ammonia, due to its toxicity can raise concerns [23]. Additionally, the support of the technology is dependent on how risks are mitigated, and benefits distributed, which indicates that the course of implementation is a vital part of the social acceptance [23].

Concerns related to public acceptance are also linked to the security of the use and storage of hydrogen since hydrogen is sometimes associated with explosivity and flammability [24]. Other studies have also investigated hydrogen and acceptance, however, this is mainly related to fuel cells in the transport sector, though they problematize the general lack of awareness of hydrogen in the public as prohibiting public acceptance amongst other factors [25]. This is also supported by Tarkowski & Uliasz-Misiak [26] who highlight social acceptance as one of the biggest barriers to the implementation of hydrogen underground storage. Several of the studies conducted on this matter state that the knowledge of this topic is very limited and needs further research due to the novelty [23], [27]. Experiences from the Fjord PtX project show that some groups of local citizens are worried about the consequences that might occur related to the type of project which shows that there is ongoing work in communicating with local citizens and ensuring collaboration [28]. Another factor limiting the expectations for acceptance of such large-scale installations is the local renewable energy production for large-scale wind and solar that might be attached to large-scale e-fuel projects [22]. In the past, wind energy has especially experienced resistance and backlash from residents [22]. Local ownership model, however, seem to increase positive qualities in community energy projects according to a study from Norway [29]. Poimakis, et al [30] highlights that multi-actor partnerships present a way forward when implementing new technology, and community ownership and public participation have a potential for increasing advocacy for the wider industry.

A critical factor for the successful implementation of PtX products is certification of the origin [31]. Abad & Dodd [32] further demonstrate that hydrogen and associated fuels must prove their low GHG emissions for them to have a significant role in the future energy system. Schemes for guarantee of origin are challenging to devise and the missing global definition of green hydrogen is adding to these challenges [32]. The emission intensity is also argued by Cheng & Lee [33] as a means to differentiate the hydrogen products, who state national hydrogen strategies must be followed by a certification scheme to have any effect

A study by Lucchese et al. [34] investigated the legal framework regarding hydrogen and associated fuels in 10 countries across the globe and presented that few have specific regulations regarding PtX and some even inhibit deployment. Research on the West Swedish process industry indicates that the development of PtX is driven by the obligation of reducing emissions and not by the European Emission Trading (EU-ETS) for CO_2 [35]. Furthermore, long-term goals of hydrogen usage through strategies are also a greater driver for green hydrogen development than CO_2 emission reduction goals [36]. According to the Danish Transmission System Operator, 'Energinet', successful diffusion of PtX in Denmark is possible if, among other things, strategies and framework conditions on the national and EU scale are clear and consistent [37]. The Danish Government mentions in their Strategy for PtX that a regulatory framework is needed to levelize PtX fuels with fossil fuels and achieve a market where funds are not needed [38]. Furthermore, they state that legislation revolving around hydrogen needs to be updated as well. This is supported by a Danish large-scale PtX project that points to the missing framework or current framework as inhibiting the implementation and therefore changes need to be instigated [39].

The Danish regulatory framework for PtX is mainly made up of already existing legislation and frames, except for the 2021 PtX strategy that comes with the funding of 1.25 billion DKK for the development of PtX projects in Denmark [38]. The Danish gathering of companies involved with PtX and hydrogen in Denmark, 'Brintbranchen', is pushing for a faster implementation of the initiatives mentioned in the strategy such as a hydrogen infrastructure, and they state that current trends and energy crisis is only underlining the need for an increased focus on e-fuel project implementation [40].

2. Scope

The existing literature on PtX and especially green hydrogen dives into aspects such as technology development, LCOE, cost optimization [41]–[48], or other factors such as supply-chain management and operational patterns [49]–[51] but does not focus on the implementation of large-scale e-fuel projects through e.g. optimal incentive structures and regulation, stakeholder engagement or importance of these and other related factors.

The literature review has stated that several studies relate to the missing regulatory frame as part of future or near-term issues for the implementation and has generally stated that this is a missing aspect of the green hydrogen pathway [4], [34], [37] highlights that market formation for sustainable fuels needs to be stimulated by regulatory frameworks. Furthermore, the environmental aspects along with social acceptance need to be considered [22]. This further relates to permitting processes as something that prolongs and complicates implementation, even though there are only a few of these large-scale projects [35], [52]. An important factor that is not highlighted relating to the implementation is the novelty of these types of projects as well as the scaling of certain technologies that accumulating with the novelty and uncertainties are driving the implementation at a slow speed. Furthermore, less attention is brought to local supporting infrastructure which covers a range of factors such as sourcing the power and connecting to the grid, excess heat disposal, synergies and engagement of local stakeholders, which are all factors that are a part of the implementation of e-fuel projects.

Recent developments in the US on tax credits for clean hydrogen with the 'Inflation Reduction Act' feature the steps towards a framework supporting PtX implementation [53]. However, several other elements in the framework should be understood before this can be viewed as a 'gamechanger' for the development of PtX, and the Act pressures many other countries, especially in the Western world to stimulate the market and conditions to support the necessary infrastructure for the e-fuel project development [54].

In a Danish setting, the market-based Power-to-X tender offering 1.25 bil. DKK has been settled, awarding the funding to four different developers and six projects [55]. The tender is directed towards the most economically and largest productions of hydrogen. The economic support is awarded as operating aid to each amount of produced hydrogen. The funding was awarded to some of the PtX projects in Denmark that are furthest along in the development and the projects have a capacity of 9-150 MW. This tender marks the development towards a Danish framework supporting the development of PtX. This is also supported by the role of the Danish Energy Agency being more clearly outlined and their engagement to support developers and authorities. This is e.g. through their work of clarifying which permissions and authorisations are needed for a PtX plant as this is one of the issues pressuring the development [56]. This thus marks an enhanced focus on the implementation process from all parties involved and highlights a pathway towards successful diffusion of the PtX technologies.

This paper investigates two e-fuel projects in Denmark to compare processes of development, incentives and project configuration to understand the implementation processes of large-scale PtX and how it might be aided to further enhance implementation frameworks. The two projects that are investigated are, 'Project HØST', in Esbjerg and the 'Fjord PtX', project in Aalborg. None of these projects have received direct support from EUR 23.5 million from the Recovery and Resilience plant, that been directed to investments in green fuels for transport and industry [57]. It is worth noting, that Copenhagen Infrastructure Partners as one of the main stakeholders in both of the investigated projects is participating in one of the funded projects [58].

3. Analytical approach

This section presents the methods used to research and analyse the problem stated above. Additionally, a definition of the implementation of e-fuel projects is included in this section to establish an adequate level of detail in this study. The approach to the analysis has been exploratory, meaning that the focus is on capturing a deeper understanding of the topic of implementation of e-fuel projects.

3.1 Project implementation process

To understand what affects e-fuel projects and their implementation, the implementation process must be defined. A study regarding energy efficiency in buildings relates to implementation as relevant from the feasibility study up until the start of construction [59]. This is relevant for e-fuel projects as there are similarities between how the projects are developed and planned. The study splits the general building process into the following phases: feasibility study, planning program, project planning and production & follow-up. The project phasing for e-fuels can be seen in Figure 1.

This means that implementation is a process that starts approximately when a project develops from a mere hypothesis into a more tangible concept. This is typically in early development where a project has been more detailed and conceptualized and further and deeper analyses are instigated. The analyses included such as nameplate capacity and the local supporting infrastructure are further defined.

This understanding of implementation is supported by Thielges et al. [60], who investigates CCU policy support in Europe and the US. They are aware of different levels of implementation, where full implementation is achieved when the technology is in operation, but the process up until operation is considered implementation, which includes the obstacles or enablers there might be on this path. The implementation process for e-fuel

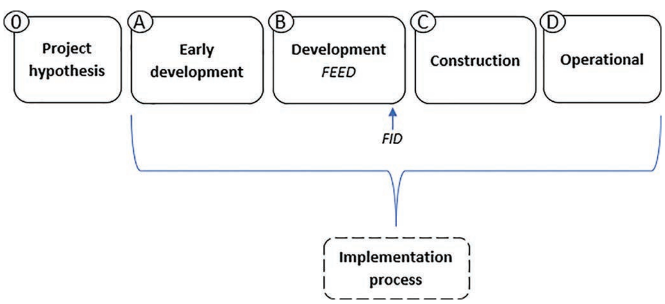

Figure 1: Project timeline of e-fuel projects.

projects covers several aspects such as policy support, planning of the project, analyses & modelling of the project configuration, stakeholder engagement etc.

3.2 Interviews

To obtain qualitative data for the analysis in this study, eight interviews were conducted. The interviewees were people with relation to PtX either by being directly involved with the two projects assessed or by having in-depth knowledge of factors that have an impact on these types of projects. A mapping of the stakeholders involved with each case was conducted to scope out candidates for the interviews. One interview was conducted in person and seven were conducted online. This is not deemed to have any influence on the results of the interviews [61]. All interviewees were asked the same questions about the implementation of e-fuel projects and what internal and external factors impact the process. This assures a higher validity of the results and ensures the relevance to later compare the results.

The method of conducting the interviews as semi-structured was inspired by Brinkmann & Kvale [62]. The semi-structured interview allows a steering on the topic of the interview through prepared questions though it still gives the interviewee the option of offering own perspectives and associations. This fits the scope of the study as the topic of implementation of e-fuel projects is broad, which means that allowing the interviewees to speak freely might induce new and unexplored topics within the field.

The interviewees have provided statements which are used in a SWOT analysis. A thematic analysis of these statements is conducted by segmentation and coding of the statements that thus are placed in different themes that allow for interpretation of the content of the interviews [63].

3.3 SWOT

SWOT analysis is a strategic management tool to understand the elements behind the implementation of e-fuel projects. SWOT can be used to understand what and how internal and external factors have an impact on projects [64]. The objective of this study has been made clear to all interviewees to ensure reliance on the results from the interviews. The SWOT analysis divides the factors into the following categories (inspired by Kenton [65]):

- Strengths: Internal factors that separate a project from others
- Weaknesses: Internal factors that hinder optimal progression in a project
- Opportunities: External factors that give the project an advantage
- Threats: External factors that can harm the project and cause setbacks

In order to thoroughly understand the factors that involve and impact the cases, data on each case should highlight different arguments, this is done through the interviews [66]. Information retrieved from the interviews must be assessed comprehensively to achieve clear evidence and arguments to be formed [66].

The analysis contributes to this study by highlighting factors that can either enhance or hinder the implementation of e-fuel projects. Strategically structuring the results of the SWOT can help steer in a direction where the results can be utilized for suggestions to aid the implementation. However, e-fuel projects are complex, with multiple different technical components and a variety of stakeholders are involved. The question of whether the SWOT analysis can capture this complexity is present, nonetheless, the structuring of the SWOT will help simplify the cases to an extent where a comparison becomes more suitable.

a) *Internal and External Factor Evaluation:* To further assess the results and the factors found in the SWOT analysis, these will be evaluated through an internal factor evaluation and external factor evaluation which is inspired by Gordon [67]. The SWOT factors are set up in two matrices – one for the internal factor evaluation and one for the external factor evaluation. *In the first step*, both the internal and external SWOT factors are assigned a weight between 0.00-1.00 with the total of these weights adding up to 1.00. The weights are assigned comparatively between the factors and are based on the relative importance of each factor. *The second step* evaluates the internal and external factors differently. The internal factors are rated according to how strong or weak the factor is within the projects:

- 4 points: Major strength
- 3 points: Minor strength
- 2 points: Minor weakness
- 1 point: Major weakness

For the external factors, a rating from 1-4 is carried out. This describes to which degree the project can respond to an opportunity or threat:

- 4 points: Superior response
- 3 points: Above average response
- 2 points: Average response
- 1 point: Poor response

Step three is a multiplication of the weight and rating of each factor, which results in a weighted ratio, which is used to describe the relative importance of each factor compared to each other. *Step four* sums the weighted ratio of the individual factors and this results in an overall weighted ratio, which indicates how well the projects perform. A total score above 2.5 is average and a score below indicates that the project is not well equipped to withstand weaknesses or threats. These steps are carried out on both projects to assess the factors and the relative importance of these. The evaluation gives an overview of which factors are more important in the implementation process and impacts the projects. However, the evaluation is subjective, and it can be difficult to assess the factors if these are too broad and not specific to the case [68].

4. Results

4.1 Cases

The following section entails a description of the cases that are investigated. An important aspect to highlight is the fact that CIP (Copenhagen Infrastructure Partners) are the developers of both projects. CIP is a fund management company that through different funds invests in renewable energy assets across the world. This makes them highly involved and notable stakeholders since the investment, in the end, relies on the company [69].

HØST PtX

Project HØST with a commercial operation date in 2026 will produce 600,000 tons of ammonia a year with an electrolyser size of 1 GW. The plant will operate flexibly according to the availability of renewable energy in the grid which means that the project will be grid-connected. The project is placed in Måde near Esbjerg and will take up to 30 ha. The project will have synergies with:

- Esbjerg Port - for discharge facilities of ammonia
- DIN Forsyning - delivery of excess heat for district heating that can cover the demand of 15,000 households
- Energinet - the project will be connected to the transmission grid
- Other interested parties are DFDS, Maersk, Arla, DLG and Danish Crown which will use the ammonia as shipping fuel and in the production of green fertilizer respectively

Figure 2 below depicts the project configuration. The synergies and flows are shown together with the overall technologies.

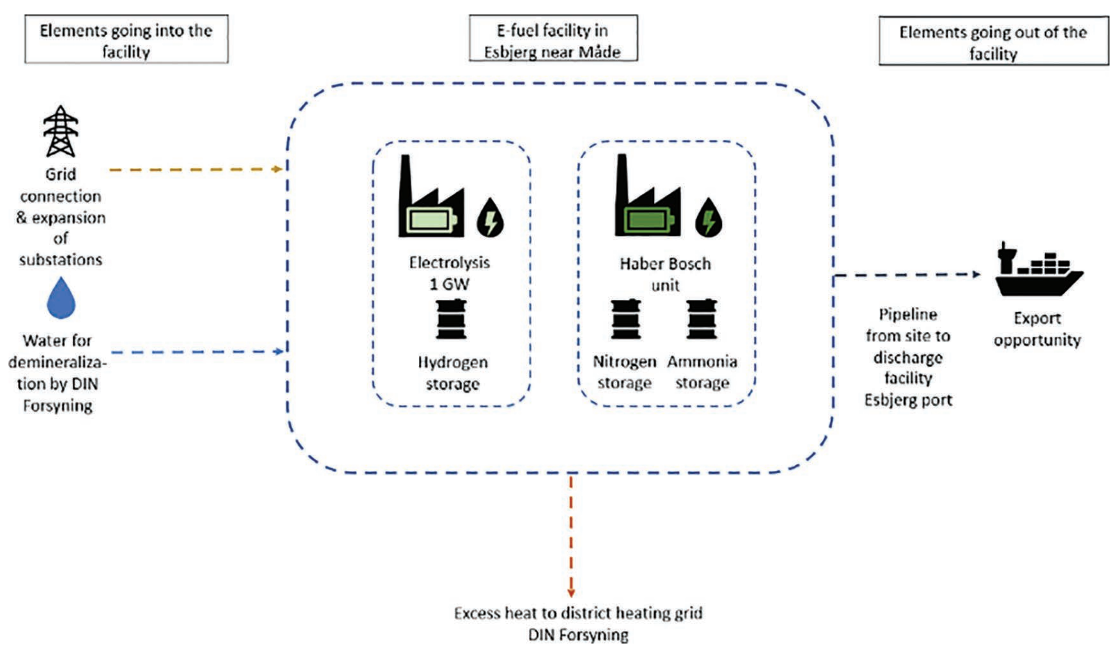

Figure 2: The configuration of Project HØST [70]

The involved parties and stakeholders of the project are represented in Figure 3.

Fjord PtX
The Fjord PtX project with the commission in 2028 will produce 100,000 tons of renewable fuel a year, and SAF (sustainable aviation fuel) is a part of this production. The

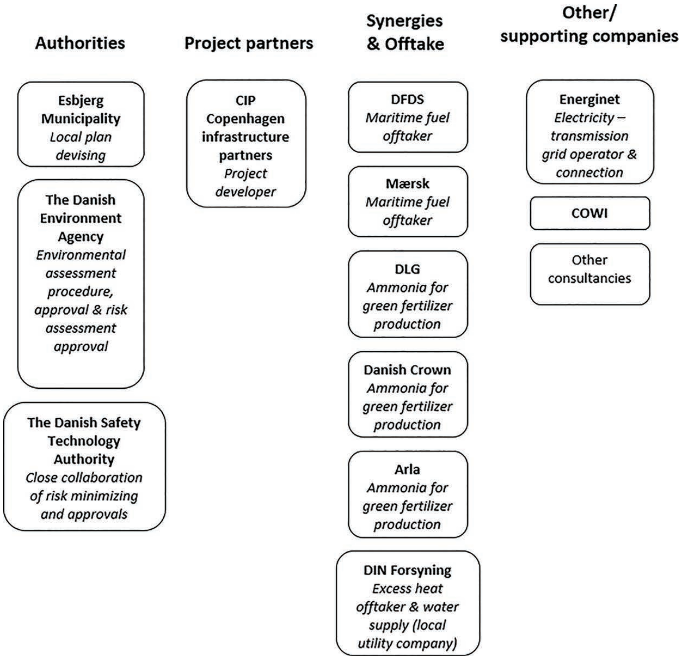

Figure 3: A mapping of involved stakeholders in Project HØST

expected electrolyser size is 400 MW and it will operate flexibly according to the volatility of the grid and renewable energy production. It is located in Aalborg next to Nordjyllandsværket north of Limfjorden in an area that totals 22 ha. The project will have synergies with:

- Nordværk - supply of CO_2 from waste incineration
- Port of Aalborg North - for discharge facilities of SAF, LPG and naphtha
- Nordjyllandsværket - due to the location of the site on their grounds
- Aalborg Forsyning - delivery of excess heat for district heating
- Aalborg Portland will deliver CO_2 to the project and receive excess oxygen from the electrolysis
- Energinet - the project will be connected to the transmission grid

Figure 4 shows a diagram of the project configuration and how the synergies fit are executed. The project is constructed with several different storage options and technical facilities. The project partners and involved stakeholders are mapped below in Figure 5.

4.2. SWOT analysis of e-fuel projects in Denmark

The interviews for this analysis were conducted with two types of interviewees; internal project employees with in-depth knowledge of these and experts with

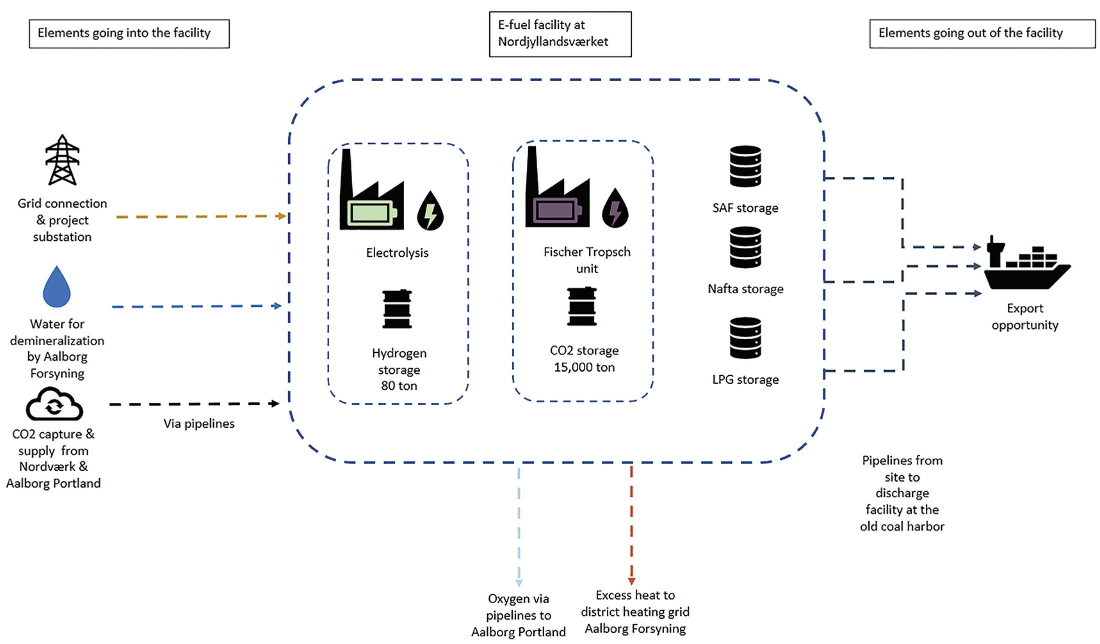

Figure 4: The configuration of the Fjord PtX project [71]

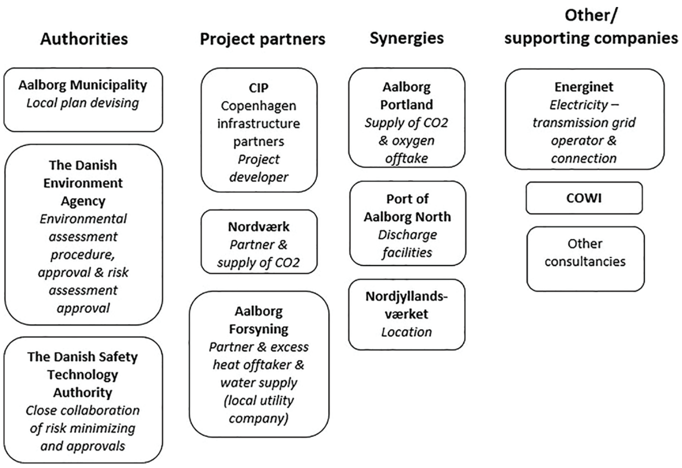

Figure 5: A mapping of involved stakeholders in the Fjord PtX project

knowledge of the general implementation of e-fuel projects. This divergence determines that the analysis of the positive and negative impacts on the projects will be carried out on a general level and not on each project. Moreover, the complexity of the projects results in diverging answers for some of the topics. This is explained and discussed further below. The results from the analysis of the SWOT factors are depicted in Table 1. The relevance of each factor according to the stage of implementation is depicted by the attached A (Early development), B (Development), C (Construction) or D (Operational). What can be deducted from the phases of each factor is that multiple SWOT factors are relevant in multiple stages of the implementation, highlighting the complexity of these factors.

Table 1: The identified factors in the SWOT analysis are divided by strengths, weaknesses, opportunities and threats

	Positive			**Negative**		
	Strengths		**Implementation stage**	**Weaknesses**		**Implementation stage**
Internal	S1	Early engagement of stakeholders and citizens	A	W1	Production is dependent on green electricity sourced from grid	**A**, **D**
	S2	Disposing of excess heat to district heating grids	D	W2	Offtake agreements are vital for business case	**A**, **B**, **D**
	S3	Ensured supply of CO_2	**A**, **D**	W3	Scaling of new and known technologies and TRL	**A**, **B**, **C**
	S4	Integration of fluctuating renewable energy with flexible operational patterns (<4000 hours a year)	D	W4	Cannot dispose all excess heat	**A**, **B, D**
	S5	Valuable locations close to synergy opportunities	**B**, **D**	W5	Continuous project planning along with planning of framework	B
	Opportunities			**Threats**		
External	O1	Denmark is a low-risk country and general knowledge-hub	**A**, **C**	T1	Share of renewable electricity in the grid	**A**, **D**
	O2	Support from municipalities and collaboration between stakeholders	**A**, **B**	T2	Market readiness and low commitment willingness from external stakeholders	**A**, **B**
	O3	General interest from industries such as low-carbon domestic flight as well as political will	A	T3	Rigid and time-consuming permitting processes not fit for this scale of projects	**A**, **B**
	O4	Framework of certification for electricity, CO2 and end-products and framework conditions of electricity tariffs and/or tax reductions	D	T4	Framework of certification for electricity, CO_2 and end-products and framework conditions of electricity tariffs and/or tax reductions	**A**, **B**, **D**
	O5	A future hydrogen infrastructure might make a part of the CAPEX redundant, but is also part of the backbone of hydrogen deployment	**C**, **D**	T5	A future hydrogen infrastructure might make a part of the CAPEX redundant, but is also part of the backbone of hydrogen deployment	**C**, **D**

A matter of the *power sourcing* of the projects showed a discrepancy between some of the external experts and internal project employees and be seen in Table 1 as points W1 and T1 of the negative impacts. The external experts point to this as one of the largest threats to the projects as the projects specifically utilize renewable electricity, and the latest surge of e-fuel projects announcement and hesitation of execution of large-scale wind and solar projects in Denmark shows a discordance of this particular matter [72]. One external expert elaborates *"One of the biggest hindrances is, do we have enough renewable electricity? When we i.e.. look at the build-out of offshore wind here and now, it is going way too slow"*. The internal project employees use the argument of projections showing that the electricity in the grid in 2028 will be 100% renewable-based and that the contributions to CO_2 emissions of the electricity sector will be marginal in 2030 [73], [74]. Furthermore one of the employees of the Fjord project discounts the external experts' view on the matter of power sourcing by saying *"There is enough renewable electricity in the grid. Above 90%. According to the framework from the EU 90% is green. And we believe it will be enough"*. The topic of green electricity in the grid further relates to the regulatory framework, point T4 under Threats, as both types of interviewees mentioned this as prohibitive of project implementation, where an external expert points to the documentation of the use of renewable energy as vital. The projects are being developed along with the European Union (EU) framework of RFNBO (Renewable Fuels of Non-Biological Origin) [75], which will depend on the share of green electricity in the grid. This highlights the problem as being a matter of timing for the parallel development of wind and solar together with e-fuel plants connected to the grid in and around Denmark. This is a matter that has increasingly gained attention by policymakers and efforts to ensure this is ensured through the delegated act under the Renewable Energy Directive which was officially adopted in early 2023 in the EU [21]. Additionally, it also raises the question of responsibility in terms of the RFNBO, and who is responsible for the development of renewable energy connected to the grid. Whether it is the e-fuel project developers who are responsible for this matter is a topic up for debate. The development of the RFNBO creates considerable uncertainties for the projects, as this impacts whether the end products will be able to live up to the CO_2 displacement standard and fully displace fossil fuels in the transport sector [76], [77]. An HØST project employee highlights this *"We are moving ahead of the regulation (...) we want to ensure that we are compliant with the RFNBO, but it is constantly evolving making it harder for us to guarantee [that we live up to the RFNBO]"*.

Furthermore, the certification of biogenic CO_2 is a question that has yet to be answered. This problem is raised by external experts that problematize the use of CO_2 from waste incineration plants and Aalborg Portland and increase the need for certification of the share of biogenic CO_2 in the end-product.

Another aspect of the regulatory framework is the permitting process. Both projects report a satisfactory collaboration with authorities, however, they also point out that the processes seem rigid and time-consuming. Additionally, the novelty of this type of project means that it has not been tested and carried out before, which does not necessarily mean that the framework should be changed. However, it does indicate that the framework is not geared for large-scale projects that involve several technologies. As mentioned by the Danish Environmental Agency *"It is important to have a matching of expectations and a hold of all factors involved (...) There is a reason why you have these kinds of processes both environmental and risk assessments (...) There is no quick fix, yet we are doing all we can to collaborate between authorities."* The framework for the environmental assessment and environmental and risk approvals is set in place, but the composition and size of the projects bring the scoping of the environmental assessment to a more important and also complex level, which is an aspect highlighted by the Danish Environmental Agency. Furthermore, these types of projects are relatively new which means that the specific procedure is being developed whilst many ambitious projects are developing and conducting environmental and risk approvals at the same time. This is a vital part of the implementation process as external circumstances can impact the development phase of the projects. The Danish Environmental Agency (DEA) has increased its focus on the complications of these projects. This has resulted in work related to highlighting which approvals are needed and which legislation is impacted through the development of PtX projects [56]. Furthermore, a task force and other groups have been formed to advance the authority processing related to PtX work and ensure the high quality of this work. Nonetheless, as several project employees point out the time aspect plays a role, since delays increase costs.

This shows that the interviewees disagree on the role that the permitting process plays in the implementation and whether or not the processes should be changed. All can agree that the regulations and rules are set in place for a reason, though some of the project employees point to the complicated procedures as time-consuming and would wish for a higher degree of collaboration to mitigate some of the issues, and project employees of the HØST project *states "The permitting process itself is rigid and not scaled for this [type of project]"*. Experts and authorities state that the processes of the area are already balanced, clear and fitted to include large projects. One expert highlights *"It is harder for all parties to work together because it is some new areas, together with the scaling [of technologies]. You have not tried that before and the process is heavy [...] But I actually believe that the current legislation can hold these types of projects"*. The interviewees agree that the e-fuel projects bring a new dimension of complexity that sets higher demands for the processes.

The local conditions in terms of excess heat delivery to the district heating grid are mentioned as both a strength and a weakness, see Table 1. Both projects can deliver a part of their excess heat to the district heating grid, as point S2 in the SWOT analysis highlights.

This creates additional revenue and from a general energy system perspective, this is favourable to obtain synergies from sector coupling. The projects can obtain synergies with local district heating companies and dispose of parts of the excess heat which relates to S5 of the internal factors *"Valuable locations close to synergy opportunities*". Other synergies with stakeholders are something that the projects are committed to. Both are involved with the local utilities, but especially Fjord PtX is working closely together with multiple companies. However, the placement of the projects in industrial districts, the large amount of excess heat of the processes in the plant and seasonal demand also means that not all the heat can be utilized. This is pointed out by several interviewees as a waste of resources since the excess heat is not inconsiderable. An external expert points to this especially in Esbjerg, where several other PtX projects are being developed in the area and it is therefore a challenge to utilize all the excess heat. This subject is also mentioned by an employee from the Fjord PtX project as one of the most immediate risks as *"we cannot sell more excess heat to the district heating grid, than what we are already planning to do"*.

A separate aspect of the local conditions is the engagement and communication with local citizens which is part of the positive impacts seen in Table 1. The HØST Project engaged the local stakeholders early on which has led to a positive attitude towards the project. This is explained by a project employee *"Early on in the process a team was set to drive the consent part of the project [...] Of course a lot is already stated in the Environmental Assessment Act. But a lot of effort is put into engaging the local community"*. The early engagement led to the finding of a suitable area for the plant as well as ensuring that the project was locally anchored. This is highlighted by both the municipality in Esbjerg and HØST project employees. Therefore, communication seems to be vital for implementation. The opportunity to explain the projects to the citizens (and local stakeholders) diminishes opposition towards the projects. This is another aspect that can prolong the implementation and planning process, where it is significant that a valuable and trustworthy relationship is built between local citizens, project developers and authorities.

A weakness that several interviewees agree upon is the scaling of technologies. The RWGS technology that is used for the production of syngas from CO_2 and hydrogen is separating the Fjord PtX Project from HØST. The technology readiness level of the technology is lower than what is desired for this scale [78]. However, the general scaling of all technologies is still rather new, and some uncertainties regarding the implementation are attached to this issue. This issue also relates to the unknown threat of other technologies in other countries which is mentioned by both a project employee from HØST and an employee from the Danish transmission operator.

Also, the e-fuel plants need to be able to ramp up production to follow renewable energy production. This is unusual for conventional thermo-chemical plants as they usually have a stable operation at nominal capacity. This poses high demands on the plants and the technologies. This relates to the fitting of the flexible production of renewable energy with the operation of the e-fuel plants seems to be an issue in the coming years where the development of wind and solar energy in Denmark will be decisive for this topic when the HØST project is commissioned already in 2026.

The risks that are attached to the configurations of the projects with new or less tested technologies are something the investors are less likely to take [79]. This causes a hindrance to progression in the project planning if all risks must be severely minimized. Since the HØST and Fjord project is developed by CIP, minimizing risks is a large part of the company's nature as an investment company. Minimizing risks is a large part of the methodology and project progression of the HØST project in particular since it is announced as one of the PtX pioneers in Denmark.

A strength of these projects is the local knowledge and support present within the projects as well as in the surrounding environment represented in the S1 point of the SWOT analysis. The local knowledge is for instance knowledge of execution of large energy projects, local conditions or other relevant knowledge of parts of the project configuration. This aspect creates a willingness to develop the projects and minimizes risks which increases the project probability eases the implementation process and aids the process progress steadily. Furthermore, supportive local authorities are a driver for the implementation of projects particularly in the early phase of the implementation process.

4.3 Internal Factor Evaluation

To further evaluate the impact of the SWOT factors explained above and the relative importance of this an internal and external factor evaluation is carried out. This allows us to compare the factors against each other and assign each of them a weight which contributes to seeing what sets the projects apart and what can be said generally on what impacts the implementation of e-fuel projects in Denmark.

The matrix in Table 2 shows the overall weighting of the internal SWOT factors and highlights Fjord PtX compared to HØST due to the weighting of 2.53 and 2.3 respectively. HØST is below the average of 2.5 which suggests the weaknesses outweigh the strengths. However, Fjord PtX is near average which recommends that the weaknesses still need to be handled.

The strength of project HØST is the early engagement of stakeholders, partners and citizens (S1), this has proved a great value for the project in the early development phase as some hindrances are mitigated. It is also worth mentioning that the disposal of excess heat (S2) and the valuable locations (S5) are strengths of this

Table 2: Matrix illustrating the weighted internal SWOT factors of both projects.

	Internal SWOT factors	**Project HØST**			**Fjord PtX**		
		Weight	**Rating**	**Weighted score**	**Weight**	**Rating**	**Weighted score**
	Strengths						
S1	Early engagement of stakeholders and citizens	0.17	4	0.68	0.16	3	0.48
S2	Disposing of excess heat to district heating grids	0.11	4	0.44	0.11	4	0.44
S3	Ensured supply of CO_2	Not relevant	0	0	0.14	4	0.56
S4	Integration of fluctuating renewable energy with flexible operational patterns (<4000 hours a year)	0.05	3	0.15	0.04	3	0.12
S5	Valuable locations close to synergy opportunities	0.08	3	0.24	0.09	3	0.27
	Weaknesses						
W1	Production is dependent on green electricity sourced from grid	0.18	1	0.18	0.12	1	0.12
W2	Offtake agreements are vital for business case	0.21	1	0.21	0.14	1	0.14
W3	Scaling of new and known technologies and TRL	0.03	2	0.06	0.09	2	0.18
W4	Cannot dispose all excess heat	0.05	2	0.1	0.03	2	0.06
W5	Continuous project planning along with planning of framework	0.12	2	0.24	0.08	2	0.16
	Total	1.00	-	2.3	1.00	-	2.53

project. The weaknesses that weigh these down are mainly the dependence on green electricity sourced from the grid (W1) and offtake agreements (W2) as this is a vital part of the business case. If both are not ensured, the project will not happen.

The strengths of Fjord PtX are the ensured supply of CO_2 (S3) since this is critical to the amount of infrastructure needed, the production of SAF and the collaboration with partners. Furthermore, a strength of the project is also the disposal of excess heat. As with the HØST project offtake agreements and dependence on green electricity sourced from the grid are great weaknesses however the scaling of the technologies in the Fjord project is a weakness of the implementation of the project (W3) since the composition of technologies in this project plays a greater role.

4.4 External Factor Evaluation

The matrix in Table 3 shows the overall weighting of external SWOT factors and highlights Project HØST thus with a score of 2.39 compared to 2.21 for the Fjord PtX project. Both are below average meaning that the threats are posing a greater impact than what the strengths outweigh. The opportunities of the HØST project are mainly present in the support from municipalities and collaboration with stakeholders (O2). This is very specific to the Esbjerg Municipality context that HØST is located in. The municipality seems very active in the planning and facilitates authorities processes that aid the project in advancing further. Several threats are deemed superior to influence the HØST project. The first to mention is the framework conditions of electricity tariffs, tax reductions and end-products (T4). This has been highlighted by the interviewees as well as a factor that prohibits optimal implementation through multiple stages of the projects. Furthermore, the share of renewable electricity in the grid (T1) and market readiness (T2) are factors that are difficult to mitigate which thereby negatively impacts the implementation as they are a vital part of the project probability.

Table 3: Matrix illustrating the weighted external SWOT factors of both projects

	External SWOT factors	Project HØST			Fjord PtX		
		Weight	Rating	Weighted score	Weight	Rating	Weighted score
	Opportunities						
O1	Denmark is a low-risk country and general knowledge-hub	0.06	3	0.18	0.1	3	0.3
O2	Support from municipalities and collaboration between stakeholders	0.17	4	0.68	0.14	4	0.56
O3	General interest from industries such as low-carbon domestic flight	0.04	2	0.08	0.06	2	0.12
O4	Integration of renewable energy using large scale flexible consumption aids both the direct and indirect electrification	0.09	3	0.27	0.07	3	0.21
O5	Potential hydrogen infrastructure can reduce part of CAPEX for new projects	0.07	2	0.14	0.06	2	0.12
	Threats						
T1	Share of renewable electricity in the grid	0.12	2	0.24	0.08	1	0.08
T2	Market readiness and low commitment willingness from external stakeholders	0.11	2	0.22	0.15	2	0.3
T3	Rigid and time-consuming permitting processes not fit for this scale of projects, and lack of resources within authorities	0.1	1	0.1	0.12	2	0.24
T4	Framework of certification for electricity, CO2 and end-products and framework conditions of electricity tariffs and/or tax reductions	0.18	2	0.36	0.16	1	0.16
T5	A future hydrogen infrastructure might make a part of the CAPEX redundant, but is also part of the backbone of hydrogen deployment	0.06	2	0.12	0.06	2	0.12
	Total	1.00	-	2.39	1.00	-	2.21

The Fjord PtX project strength is also the support from municipalities and stakeholders. The framework is not deemed to have the same weighted score as within the HØST project which might be because the planning process is not as far along or the indication that this will be changed when the project is expected to be operational. The rigid permitting processes (T3) are then highlighted as well as market readiness, but the share of green electricity in the grid is not. This is partially because this project is operational later than HØST where projections for the expansion of RE in Denmark are favourable for Fjord PtX.

5. Discussion

Analysing SWOT factors in several phases of development and planning of e-fuel projects in Denmark contributes to understanding what affects the implementation of these projects. The analysis showed that the following factors are the most pertinent:

- The e-fuel projects source electricity directly from the transmission grid in Denmark and thereby risk compliance with RFNBO to meet 90% green electricity in the grid
- There are many uncertainties linked to the development of e-fuel projects such as market readiness (willingness to pay for the products) and the basis of a future market in Denmark
- Large interest in the projects and collaboration with partners, business partners and stakeholders positively influence the implementation process through clear and decisive communication
- Uncertain and adamant regulatory framework conditions prohibit optimal planning of projects. This is elements such as CO_2 taxes, RFNBO and electricity tariffs for consumption

The discrepancy between the interviewees of green electricity in the grid highlights that it is a matter of importance. However, the pipeline of new wind and solar projects is well enough to cover the increasing electricity demand, so it seems to be a matter of timing the connection of the e-fuel plants together with wind farms and solar PV parks [80]. The competencies to further develop renewable electricity projects lie within CIP, so they could be able to solve this issue themselves or contribute to the development.

Two of the other largest e-fuel projects in Denmark (1.3 GW and 10 GW) both have generating assets as part of the project configuration, which could suggest that this is a vital part of the implementation when these sizes of electrolysers are to be implemented in a Danish context [81], [82]. However, two other projects on 350 MW and 1 GW electrolysis are also not erecting solar or wind energy in connection with their projects, which further complicates this topic [83], [84]. The decarbonization and resilience of the grid is also a matter of concern from a European perspective [85]. The potential congestion of the onshore grid from incoming offshore installations is highlighted as one of the constraints for development and is thus linked to the overall challenge of deploying enough renewable electricity capacity for reaching climate and hydrogen goals.

For compliance with framework conditions and the e-fuel projects reducing CO_2 emissions, it is important that the CO_2 utilized to produce SAF can be accounted as biogenic, so it does not induce dependence on non-biogenic sources and thereby continuous use of fossil fuels. For the projects to compete in the fuel market the product must be either directly comparable with the fossil-based alternative in terms of price or that funding or tax credit exists to lower the price. This further relates to the regulatory framework that in multiple ways seems to be a hindrance for the implementation of these projects rather than an instigator.

The PtX strategy from the Danish government Implies this particular subject should not be a problem for the projects. However, this is the case more than 2 years after the strategy was published, thus changes within infrastructure expansions, authorities processing and reduction of electricity tariffs, amongst others, are desired by people involved with the business of the e-fuels.

However, the DEA has instigated several initiatives to ensure the implementation process. This is e.g., through originating task forces and providing an overview of the necessary approvals and legislation impacted by the e-fuel projects. All initiatives have the objective of heightening the quality of the work related to the authority processing from all parties involved both private and public [53]. Development of the hydrogen infrastructure to join the Hydrogen Backbone could potentially stall some of the project's inauguration as the timeline for the Danish part of the infrastructure is still unclear. On the European level, movements related to ensuring the regulation of international hydrogen markets, were initiated at the end of 2023 with the proposal from EC [86].

Another important aspect of the success of the implementation of the projects is the engagement and interest expressed by local stakeholders and citizens. This largely seems to be able to mitigate or ease a range of obstacles in the implementation process and therefore this element should be an aspect that is regarded more highly in the planning and development of the projects than the literature states currently. The analysis of SWOT factors in this paper is however not an extensive investigation of factors that impact the implementation of the e-fuel projects used as cases in this regard.

To fully conclude which factors are decisive for the diffusion of e-fuel projects in Denmark, related analyses of additional e-fuel projects in Denmark would be relevant. However, several of the interviewees in this paper have answered on the background of their general knowledge of e-fuel projects and not with specific regard to either Project HØST or the Fjord PtX Project. This increases the reliability of the study.

Another relevant aspect of this study and investigation of two e-fuel projects in Denmark is the relative complexity of each project. In the cases examined for this paper, both the sizes and combination of the technologies highly increase the complexity of the projects which complicates the development and planning of the project. This will in turn also impact the implementation. Furthermore, this influences which stakeholders are involved in the projects, and means that more people are involved, which again increases the complexity. The regulatory framework in terms of permitting, grid connection, environmental impact assessment, etc. are all challenged due to the novelty and complexity.

Furthermore, the complexity makes it difficult to compare each project since there are divergent factors in each case which will influence the complexity in different ways, such as the local conditions. The local conditions are especially difficult to compare in the two cases since the Aalborg Municipality was not interviewed. The analysis shows that having a supporting local environment is valuable for the implementation process. Esbjerg Municipality is a visible stakeholder as a facilitator to attract large industries and is aware of its role in these processes to increase the collaboration and ease permitting processes as they are allowed to within the framework. of the contact was not established with Aalborg Municipality which raises some uncertainties on the general understanding of how the municipalities play a role in the implementation process of these e-fuel projects. However, documentation shows that the municipality has a positive position towards the projects, especially due to the level of potential job creation that the project will bring to the municipality [87].

It would be interesting to understand the level of support and collaboration they contribute to the Fjord PtX project, as the HØST project seems to benefit from the collaboration with Esbjerg Municipality. The collaboration has a positive effect on the implementation as processes are eased.

6. Conclusion

This paper describes what factors have the greatest impact on the implementation process of two e-fuel projects in Aalborg and Esbjerg. Interviews with employees, experts and authorities created the basis for a SWOT analysis in section IV and internal and external factor evaluation that presented the e-fuel projects' early engagement of stakeholders and ensured CO_2 supply as a strength of the projects. Current uncertainties of market readiness, offtake agreements and share of renewable electricity pose weaknesses to the projects on an economic and technical level. Threats to the projects can be found in the often rigid and unfit regulatory framework conditions, and thus a willingness through the Danish PtX strategy still is not working in favour of implementing e-fuel projects. Moreover, EU regulation such as the RFNBO creates uncertainties for the projects that are close to final investment decisions, as they wish to be compliant with future regulative framework conditions that impact these projects.

To diminish threats and weaknesses it can be observed that stakeholder collaboration can largely mitigate this, which is also one of the greatest strengths within these projects. Collaborating with authorities and having clear communication helps the permitting and regulatory processes to the extent possible. Creating agreements with possible offtake companies through collaboration is also a substantial part of diminishing the weakness by ensuring the e-fuel product can be disposed of. The large interest and support that the projects are experiencing is a part of the opportunities for these projects showing that there is a lot of willingness present across the value chain of the projects which can help the projects develop.

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