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Towards sustainable feasibility studies for P2X investments

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ABSTRACT

Investments into new energy solution systems, and for example into producing carbon-neutral fuels, are increasing, but tools for the capital investments' feasibility studies are limited. Various contemporaneous attempts to reduce the dependence on fossil energy sources are needed, and a power-to-x (P2X) solution, which is part of the hydrogen economy, can be seen as one opportunity. However, many hydrogen economy solutions have not yet been proven to be economically profitable, but they could be if the investment projects were considered from a broader perspective than from company level and an economic perspective. In previous research, a three-stage economic and technology emphasized feasibility study (FS) framework has been created, and the early results indicate that the P2X investments can meet economic feasibility with over 12% of the investor IRR, and could offer profitable solutions towards a carbon-neutral future. However, the framework did not recognize the full potential of P2X through sustainability, and therefore a new extended version of the framework is needed. The objective of the paper is to create an expanded sustainable feasibility study (SFS) framework from the FS framework to support the P2X investments. As a result, an SFS framework is created, considering the investment projects' feasibility beyond the economic perspective by adding all three dimensions of sustainability: economic, environmental, and social. The three stages of the framework are ecosystem profiling, business model description, and profitability modelling. This paper was made by utilizing the design science research (DSR) methodology and a literature review.

1. Introduction

Recent developments and research activities have pursued a sustainable and carbon-neutral future where the hydrogen economy is expected to play a key role. The discussion about the opportunities of the hydrogen economy and energy storage to reduce fossil fuels and decrease carbon dioxide (CO2) emissions has been active recently (see e.g. Decker et al., 2019; Hombach et al., 2019; Salladini et al., 2020). However, there have been argumentations whether these solutions could meet the economic feasibility and which solutions would be cost-efficient or economically feasible and business-wise when pursuing decarbonization. Different P2X technologies have been studied mainly from technical perspective, evaluating the performance and efficiency of these technologies, but also some economic evaluations have been done (see e.g. Bedoić et al., 2021; Götz et al., 2016). Many hydrogen economy solutions have not yet met economic feasibility in recent research (Lester et al., 2020).

P2X technologies can be one option to promote hydrogen economy by producing synthetic liquid fuels to replace fossil fuels. Some research indicates that there is still a need for liquid fuels in certain transportation sectors, such as aviation, marine, and heavy-duty transportation (Decker et al., 2019). P2X technology makes it possible to produce carbon-neutral synthetic liquid fuels from CO2, water (hydrogen), and green electricity. P2X technology enables the production of synthetic methanol that can be further refined for example into gasoline, diesel, or kerosene. Carbon neutrality can be achieved if the fuels are produced for example from waste or by-product CO2 and hydrogen from the industries, or the hydrogen can be produced by electrolysis, using green electricity. The cement industry (Farfan et al., 2019), along with the pulp and paper industry, has great potential for

Abbreviations: P2X, power-to-x; SFS, sustainable feasibility study; FS, feasibility study; DSR, design science research; CO2, carbon dioxide; BMC, business model canvas; JPP, Joutseno pilot plant; DCF, discounted cash flow; CAPEX, capital expenditures; OPEX, operational expenses; NPV, net present value; IRR, internal rate of return; MEAE, Ministry of Economic Affairs and Employment; SEP, sustainable ecosystem profile; SBMC, sustainable business model canvas; SCF, sustainable cash flow.

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CO_2 capturing and utilization.

The transition to producing and utilizing P2X-based fuels requires that the production must be realized cost-efficiently, and the investment must be profitable acknowledging all the actors involved in the ecosystem of P2X fuel production. This includes the actors in the supply of raw materials and other resources, the producer with technological competence, customers, and other stakeholders. Thus, it is necessary to understand the ecosystem that is formed around the technology and fuel production and to pursue realizing the fuel production in a way that is sustainable to each actor in the ecosystem. The collaboration of the actors should take advantage of the circular economy.

To be able to understand and evaluate the ecosystem, cost-benefit, and sustainability around P2X fuel production, some feasibility evaluating tools are needed. According to McLeod (2021), there is a growing amount of literature on the (front-end) planning of investment projects, but there is a lack of literature focusing on feasibility studies, even though they are critical for developing novel and complex projects. Götze (2015, p. 9) introduces a capital investment decision-making framework that covers the whole capital investment process from the planning to monitoring phases. However, in this research, the goal is to drill down to represent tools to understand and evaluate the capital investment project's feasibility, which is the "project screening" phase in Götze's seven-phase decision-making process.

Based on the literature, there is a lack of research on feasibility studies (McLeod, 2021), established sustainable business evaluation models (Cardeal et al., 2020; Geissdoerfer et al., 2020), and on whether P2X solutions could meet economic feasibility today (Decker et al., 2019; Hombach et al., 2019; Lester et al., 2020; Salladini et al., 2020). This paper covers the research gap in the intersection of all these three areas by studying a sustainable feasibility study framework for P2X investment projects. The objective is to cover the research gap by developing the SFS framework to support investments projects' feasibility evaluation in P2X technologies. It is made by expanding the previously created three-stage economic and technology emphasized FS framework into an SFS framework that considers the investment project's feasibility more sustainably (such as including economic, environmental, and social dimensions in the framework) and comprehensively (such as including the perspectives from ecosystem profile level into profitability level in the framework).

2. Literature review

2.1. Ecosystem profile

There are different ways to describe ecosystems, such as cluster, value network, and business ecosystem (Möller and Halinen, 2017; Peltoniemi, 2004). According to Peltoniemi and Vuori (2008) and Talmar et al. (2020), a business ecosystem is considered a much broader entity than a geographically limited cluster or narrowly focused value network. Suominen et al. (2019) define the business ecosystem as the "cooperative and competitive activities of multiple organizations that belong to different industries". Based on Ritter et al. (2004) business ecosystems are constructed of four elements: activities, actors, positions, and links. The activities are the actions to be undertaken, and the actors are entities that undertake the activities. The positions are the actors' location in the system, and links are transferred across the actors. Adner (2017), Konietzko et al. (2020) and Jacobides et al. (2018) also share this four-element business ecosystem construction concept. In a simplified manner, business ecosystems consist of actors and their relationships with each other. The relationship between the actors can be collaborative as well as competitive. However, because of the continuously changing environments, the actors are increasingly developing collaborative relationships or synergies to be able to more effectively respond to the changing conditions (Huang and Wilkinson, 2013). Understanding the business ecosystem and having synergies in the ecosystem enables the actors to exchange knowledge and innovate, and therefore collaborate and/or compete sustainably (Moore, 2006; Wulf and Butel, 2017). Ritter et al. (2004) suggest that there are four types of relationships between actors: leadership relationship, no relationship, mutual relationship, and followship relationship.

Together the actors form a complex network where the actors interact with each other depending on their relationship. Due to the complexity of the network, an ecosystem map has been developed; its goal is to represent the system in a visual, more comprehensible format (Iyer and Basole, 2016). Iansiti and Levien (2004) have found a challenge in determining the precise boundaries of an ecosystem map due to the ecosystem map's complex structure and dynamic nature. However, Ylönen et al. (2021) have created an ecosystem profiling framework to avoid major challenges and facilitate ecosystem profiling. The six steps of ecosystem profiling are: defining value proposition, identifying core companies, exploring related companies, visualizing relations, defining additional data to be collected, and collecting data.

There is a discussion (see e.g. Parida et al., 2019; Shi et al., 2021; Tolstykh et al., 2020; Zaoual and Lecocq, 2018) that indicates that the ecosystem view must start from a sustainable and holistic perspective, and the whole ecosystem should be sustainable and profitable in the long run. Therefore, circular economy thinking needs to be merged into ecosystem thinking.

2.2. Sustainable business model canvas

A business model can be defined as "the rationale of how an organization creates, delivers and captures value" (Osterwalder et al., 2010, p. 14). Traditionally business models are economic-oriented, but today's transition towards sustainability targets has raised the need to also consider the ecosystem and circularity perspectives in business model development. Also, based on the literature, there is a clear need to include sustainability dimensions in today's companies' business models (see e.g. Bocken et al., 2019; Evans et al., 2017; Joyce and Paquin, 2016; Pieroni et al., 2019). However, there is also a discussion that shows that companies have failed to integrate sustainable thinking into their business models. (see e.g. Pain, 2014; Whiteman et al., 2013).

It has been stated that there is no established model to map a sustainable business model (Cardeal et al., 2020). Researchers such as Cardeal et al. (2020) and Joyce and Paquin (2016) have developed and proposed tools for sustainability-oriented business model innovation. Triple-layer BMC (TLBMC) presented by Joyce and Paquin (2016) adds environmental and social (stakeholder) layers into the original BMC presented by Osterwalder et al. (2010). Their triple-layered canvas aims to describe how to create economic, environmental, and social value. The business model canvas for sustainability (BMCS) presented by Cardeal et al. (2020) includes the three dimensions of sustainability in one BMC, and they propose a procedure to assess (long-term) sustainability. Other researchers have proposed their solutions to consider sustainability aspects as well, by adding and dividing the elements in traditional BMC (Foxon et al., 2015). Including the dimensions of sustainability in business model development is increasingly discussed in the literature. Konietzko et al. (2020) describe how business models can be expanded into an ecosystem level that goes beyond the given company perspective and pays attention to the business models of other relevant actors by looking at how a multitude of business models could be combined to achieve a collective outcome.

2.3. Sustainable evaluation of profitability

Understanding the ecosystems and business models is not enough in the capital investment project feasibility evaluation process. Profitability estimation is a major part of any investment planning process. Götze (2015, p. 3–6) describes the capital investment project being a set of cash outflows and inflows starting from the cash outflow, the initial investment cost, followed by cash inflow and/or cash outflows in subsequent periods (usually years). Since the investment projects can be categorized in many ways (Götze, 2015, p. 6), they may need a different investment evaluation method to correctly assess their value, impact, and profitability (Baresa et al., 2016). Laaksonen et al. (2021) have found that the discounted cash flow (DCF) model is good for evaluating the profitability of P2X investment projects, but the model is lacking sustainability focus and scope. These sustainability elements can be added to the traditional cash flow (see Equation (1)).

According to Scott (2013) and other newer research (see e.g. Atz et al., 2019; Yadav et al., 2017), sustainability positively affects the profitability of a company and project, but still, there is a lack of profitability models that would highlight and differentiate the factors of sustainability. Equation (1) shows the DCF model's mathematical representation.

$$DCF = \sum_{n=1}^{\infty} \frac{CF_n}{(1+r)^n} \tag{1}$$

where CF=Cash Flow, €; r = Discount Rate; n = Time in Years.

3. Materials and methods

3.1. Research design

The research applies the design science research (DSR) methodology the main idea of which is to study existing artefacts and develop new ones to solve pragmatic problems that people encounter (van Aken, 2004). Johannesson and Perjons (2014) introduce that the artefacts can be described as human-made objects that are applied as solutions to pragmatic problems. Hevner (2007) presents the three cycles of DSR that must be identified and presented when making a DSR research project. The cycle of relevance connects the contextual environment of the research project to DSR, and the cycle of rigor connects the research knowledge base to DSR. The cycle of design utilizes information and data from the other cycles and evaluates and builds the processes and design artefacts of the research (Hevner, 2007).

This study uses DSR for researching feasibility evaluation models and creates the SFS framework for P2X investment projects. The design artefacts are the created sustainable models which are combined into a single framework. The P2X project is based on the Laaksonen et al. (2021) feasibility study report on P2X, particularly the Joutseno pilot plant (JPP) scenario. The models for the SFS framework were selected based on their fit for the P2X investment projects, which was done earlier in the Laaksonen et al. (2021) research. However, the used models lack a sustainability perspective, which formed the need for developing the original models to meet the requirements of sustainability, such as including economic, environmental, and social perspectives. New sustainable models were created based on the literature review on the selected models, sustainability, and current updated versions of the selected models created by other researchers (see Fig. 1).

4. Feasibility study framework application to Joutseno pilot plant

4.1. Feasibility study framework and Joutseno pilot plant scenario

Laaksonen et al. (2021) have researched the P2X markets and potential business models that were analyzed together with techno-economic analysis. The market survey was conducted as semi-structured interviews, where a total of 12 interviews were conducted in six organizations and with 13 people who covered the fields of oil and energy industry, representing both the demand supply-side in engineering and manufacturing companies. These 13 interviewees were chosen based on their expertise in the fuel market and their insights into the fuel market's future developments. The themes of the interviews covered P2X products, supply side, demand side, business models, price, and sales contracts. The aim was to get insights into the current and future P2X fuel markets. The overall goal was to create an understanding of the ecosystem around P2X fuel production, the business models which could be created, and how the pricing and demand of P2X fuels will develop in future markets to support the profitability analysis. Based on these three sub-areas, the FS framework was created (Fig. 2).

Based on the interviews, the industrial-size P2X pilot plant JPP scenario was made. The scenario represents carbon-neutral fuel production in the pilot plant to be built in Joutseno. The hydrogen is sourced from Kemira located in Joutseno, and the CO2 is captured from the Finnsementti cement plant in Lappeenranta. The hydrogen is excess hydrogen produced in the electrolysis of water for chlorate production. The JPP produces methanol which can be further refined into gasoline, kerosene, or diesel by using different syntheses. The production partners have been identified in the project, which makes the JPP scenario the most applicable for implementation (out of six scenarios). The success of the JPP scenario is based on the low cost of hydrogen and the positive application of the recast renewable energy directive 2018/2001/EU (RED II) regarding synthetic fuels (Laaksonen et al., 2021). The schematic overview of the studied pathways is shown in Fig. 3. The technical overview of the process can be found in the research of Laaksonen et al. (2021).

4.2. Ecosystem map application

In the JPP scenario, the value proposition is carbon-neutral fuels management for road and marine transport and aviation. The core companies around the selected value proposition are the P2X Joutseno plant, the main raw material (hydrogen and CO2) providers, and key customers (fuel distributors). Related companies are other raw material (water, electricity, and steam) suppliers, service providers, public authorities, research partners, financiers, and other possible partners. Potential technology suppliers for electrolysis, CO2 capture, methanol (MeOH), and fuel synthesis are listed in Appendix 1 (Laaksonen et al., 2021). After identifying core (dark blue) and related (cyan blue and light blue) companies, the relationships can be visualized. The formed ecosystem map is presented in Fig. 4. In the ecosystem map, the boundaries are set to include only known actors, so there are no level 2 related companies listed nor empty nodes. The known partners are listed with bullet points and included in a single rectangle to save space.

4.3. Business model canvas application

Based on the fuel market insights from the interviews, BMC was created for the JPP, see Fig. 5 (among other scenarios). The value proposition of the JPP scenario is to produce carbon-neutral fuels for road and marine transport and aviation. The goal is to produce drop-in fuel without limits in blending and distributing it from existing infrastructure, similarly to liquid fossil fuels. Since the JPP is strongly connected to circular economy principles, the raw material supply is infinite. The scenario provides both a first-mover advantage and brand benefits for clients investing early into the production of synthetic liquid fuels. The value creation process involves synergies and collaboration between a wide range of organizations and companies. The cost structure includes the cost of hydrogen, CO2, electricity, operations and maintenance, warehousing, and production logistics. The revenue streams would consist of sales for periodically fixed prices from key partners and additional sales from side-streams (Laaksonen et al., 2021).

4.4. Profitability model (DCF) application

According to the expert interviews in the research of Laaksonen et al. (2021), the fuel demand starts growing in 5–10 years and grows for at least the next 15 years. Therefore, a significant change in demand is estimated to happen in the early 2030s. During these next 10 years, the prerequisites for the production of P2X fuels have to be tested and implemented to enable full-scale production. According to the

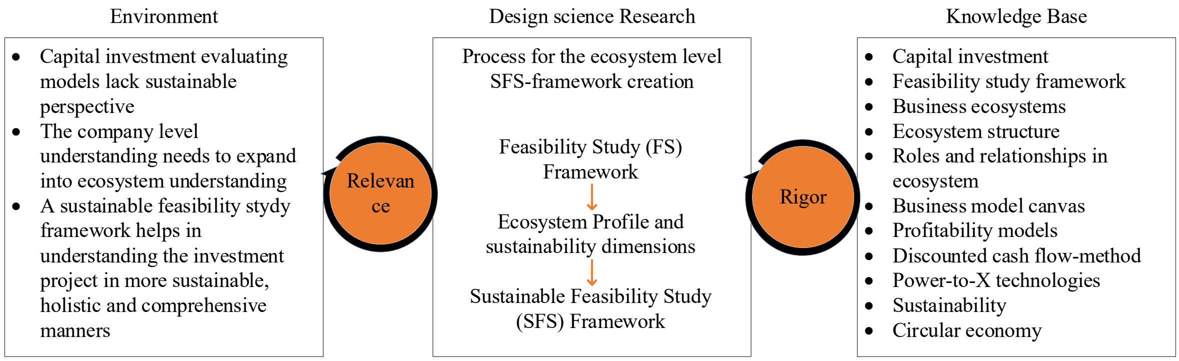

Fig. 1. DSR cycles for SFS framework.

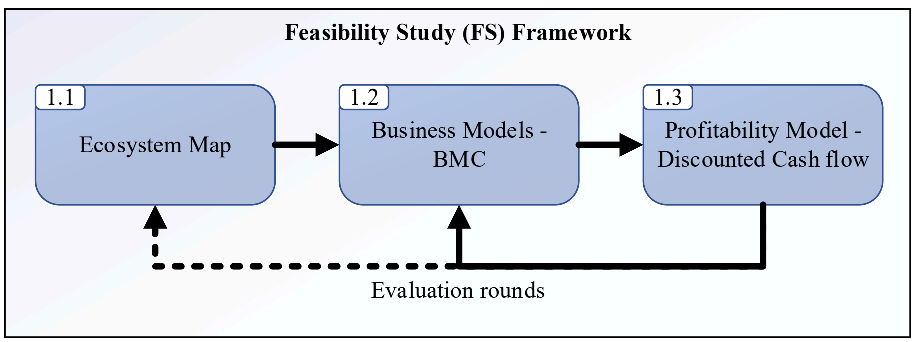

Fig. 2. FS framework.

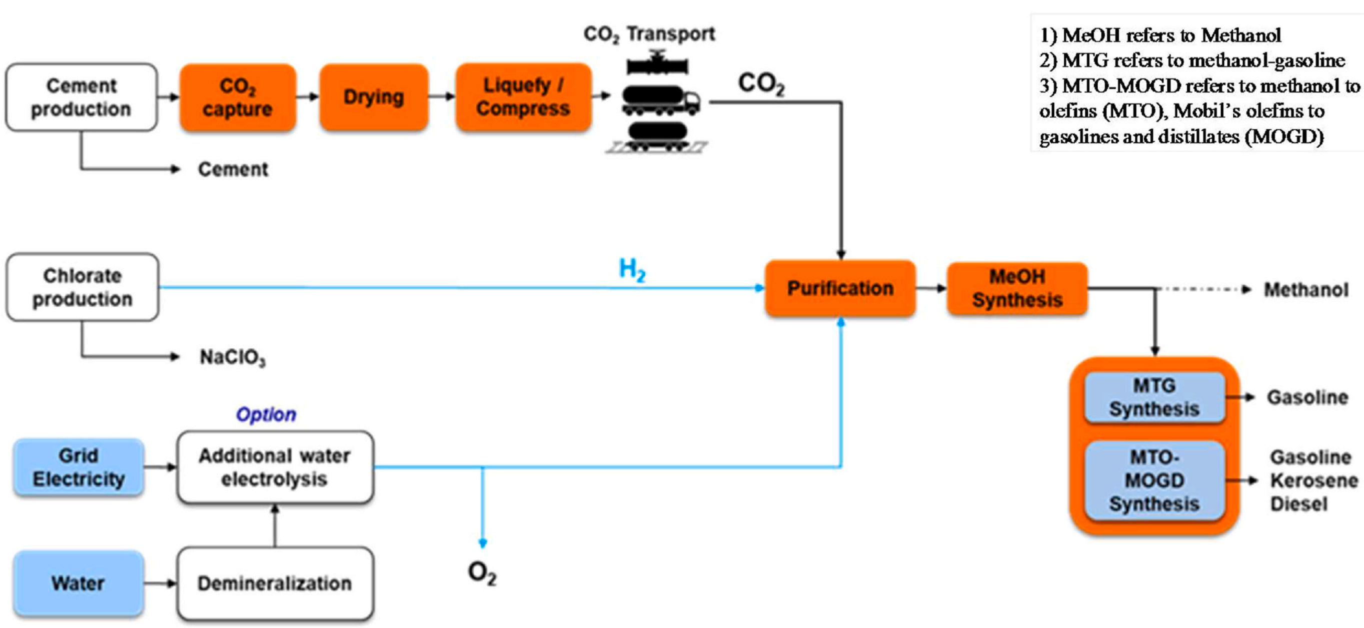

Fig. 3. Schematic overview of the studied pathways (Laaksonen et al., 2021).

interviewees, P2X fuels are likely to get the premium price through regulation, and thus compete with advanced biofuels. However, currently P2X fuels are not included in the premium price. The price evaluation for P2X fuels is difficult since there is no market or price for P2X fuels at the moment. The production volumes of competing fuels and regulation have a high impact on P2X fuel price development (Laaksonen et al., 2021).

The profitability calculation for the JPP scenario was done by using the DCF method which utilizes the elements of capital expenditures (CAPEX), operational expenses (OPEX), and demand expectations from the market survey. The cost analysis started with requesting budgetary offers from equipment suppliers and Aspen Plus modelling. Investment costs were calculated by using the simulation models. After the costs were verified, OPEX and CAPEX costs were determined and used in the profitability model. Revenues were estimated based on the presumptions that P2X fuels get a premium price and the market for P2X

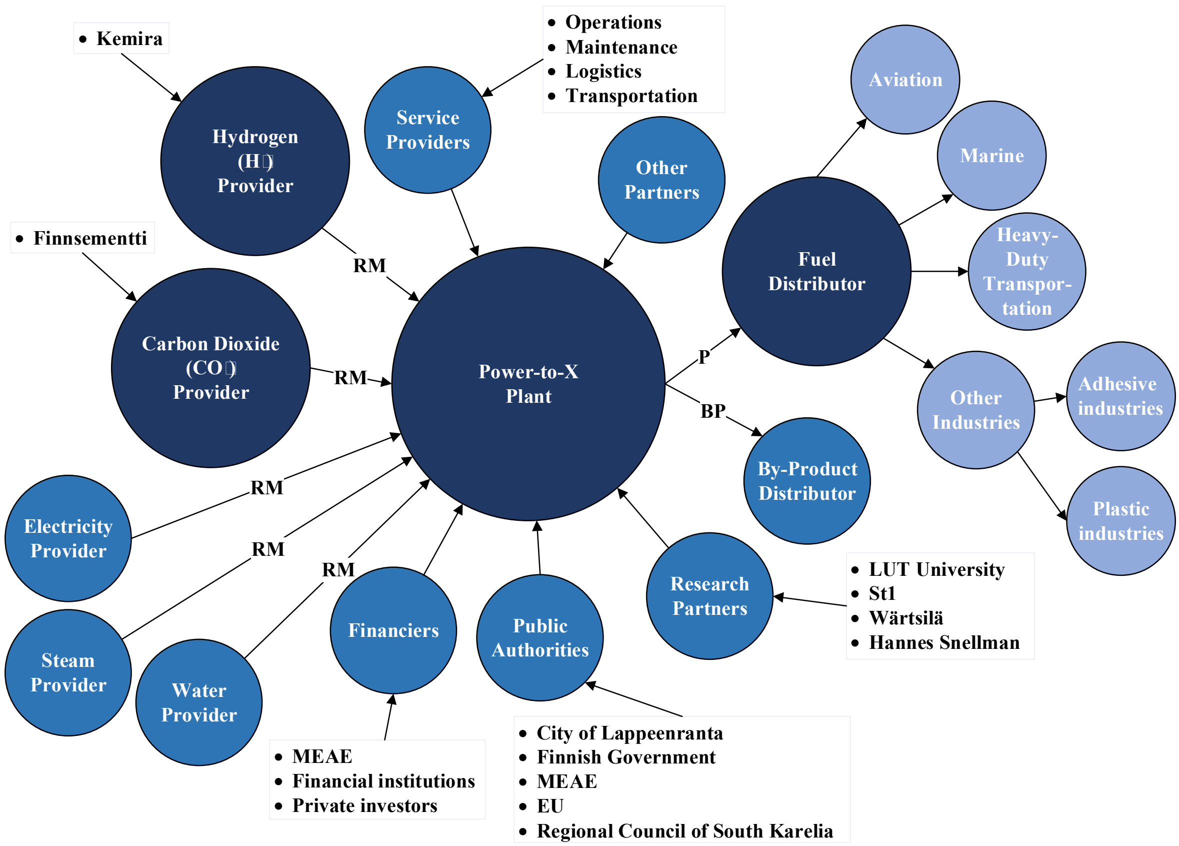

Fig. 4. Ecosystem map for JPP scenario (cf. Laaksonen et al., 2021).

fuels exists. In the profitability calculation, the supposition is that JPP's end-product is gasoline, and its operation time is 20 years. In the analysis, key figures, for example internal rate of return (IRR), net present value (NPV), and sensitivity analysis, were calculated. Key source data can be seen in Appendix 2. The annual production amounts and consumptions of steam, electricity, CO2, and hydrogen are based on Aspen modelling.

The key figures which evaluate the profitability of total investment are IRR (investment and investor point of view), NPV, payback time, and benefit-cost ratio (B/C ratio). Based on the decision criteria for each key figure, the JPP investment is profitable with the selected input values. The "base case" investment included a 40% subsidy from the Finnish government (MEAE), and the remainder is financed by 70% debt and 30% equity. Also, the investment included a 15% contingency reserve, and the revenues are based on the premium prices. The weighted average cost of capital (WACC) was used as the interest rate, and by comparing it to IRR, the profitability can be evaluated. The NPV was calculated to be around 21 million euros, and the cost of equity was defined as 6%.

Based on the one-variable sensitivity analysis, the most critical factors are hydrogen price, operation time, selling price (gasoline), and total investment. Electricity price is not as significant since hydrogen is not produced by electrolysis but bought as residual hydrogen from the chemical industry. The sensitivity analysis compares one variable at a time to the base case values and represents the impact on the investor IRR. Because of the interests of private investors, the main results are presented in light of investors' IRR. The variable ranges are estimated based on which could be seen as realistic value scenarios. If hydrogen price increases close to €1 per kilogram or gasoline price drops under €1100 per ton, the investment's IRR becomes negative, which means that the investment is unprofitable. However, the sensitivity analysis shows that the investment is profitable with almost all realistic one-variable value changes.

5. Framework development

5.1. Sustainable feasibility study framework

While conducting their research, Laaksonen et al. (2021) noted that the models used in the FS framework lack a sustainability perspective although it has an impact on feasibility. This formed the need to expand the original models to meet the requirements of sustainability, such as including economic, environmental, and social perspectives. The new extended version of the FS framework was made based on the research of Laaksonen et al. (2021) and the literature review. In the new advanced framework, the structure stays the same but the models inside the framework are sustainable and give a more holistic and comprehensive understanding of the project's feasibility.

In Fig. 7, the original framework is focused mainly on the economical perspective (colored with blue), but the advanced framework combines all sustainability dimensions: economical (blue), environmental (green), and social (yellow). Also, the ecosystem map is extended into an ecosystem profile which is a broader entity than the ecosystem map. The arrows represent the order the framework should be used in. The order starts from the ecosystem understanding and drills down into profitability modelling. The arrow below the figures represents an evaluation round. Capital investment planning usually takes more than one attempt to find the best solution or outcome; this can be seen as a constant control phase. When the evaluation round is done after 2.3, it usually has a larger impact on 2.2 (normal arrow) than 2.1 (dashed arrow). The previous evaluation rounds should be further developed while the understanding evolves during the process.

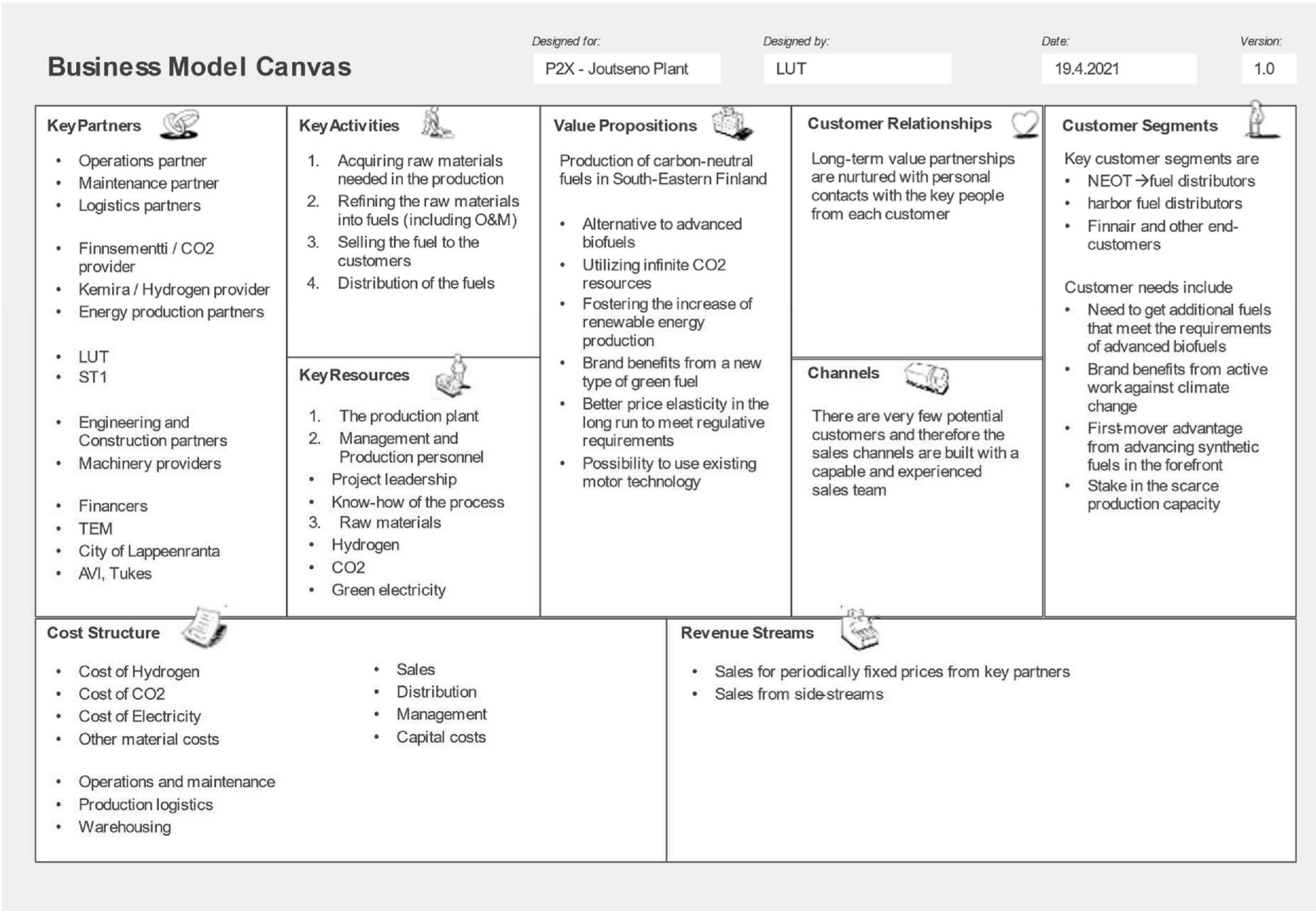

Fig. 5. BMC for JPP scenario (Laaksonen et al., 2021).

				Base case			
Electricity price €/MWh		**20**	**30**	**40**	**50**		
IRR (investor)		14,4 %	13,3 %	12,1 %	11,0 %		
Hydrogen price (€/MWh)			**10 (0,3 €/kg)**	**15 (0,5 €/kg)**	**20 (0,6 €/kg)**	**25 (0,8 €/kg)**	**30 (1 €/kg)**
IRR (investor)			16,7 %	12,1 %	7,3 %	2,1 %	-3,9 %
Total investment (reserve)	**-30 %**	**-15 %**	**0 %**	**15 %**	**30 %**		
IRR (investor)	43,9 %	27,4 %	18,2 %	12,1 %	7,8 %		
Gasoline (€/tn)	**1000**	**1200**	**1300**	**1400**	**1600**	**1800**	
IRR (investor)	-9,1 %	3,0 %	7,7 %	12,1 %	20,5 %	28,4 %	
Debt rate			**1 %**	**2 %**	**3 %**	**4 %**	**5 %**
IRR (investor)			13,3 %	12,1 %	11,0 %	10,0 %	9,0 %
O&M				**2% & 3%**	**3% & 4%**	**4% & 5%**	
IRR (investor)				12,1 %	7,8 %	3,3 %	
Operation time		**6000**	**7000**	**8000**			
IRR (investor)		2,2 %	7,4 %	12,1 %			
Investment subsidy (TEM)			**30 %**	**40 %**	**50 %**		
IRR (investor)			9,1 %	12,1 %	15,9 %		

Fig. 6. Effects of the variables on IRR (investor) through one-variable sensitivity analysis (Laaksonen et al., 2021).

5.2. Sustainable ecosystem profile

The main purpose of the ecosystem map is to visualize a complex network of actors and their connections in the ecosystem in an easier and more understandable form. In the ecosystem map, the nodes represent actors, and the lines represent connections between the actors. Actors can analyze their own business along with the success and strength of their partners, suppliers, and competitors by using the ecosystem approach (Mäkinen and Dedehayir, 2012). Ylönen et al. (2021) have found that traditional industry boundaries are fading away and rivalry between individual actors has shifted to a rivalry between ecosystems. This is because the continuous need for innovation has

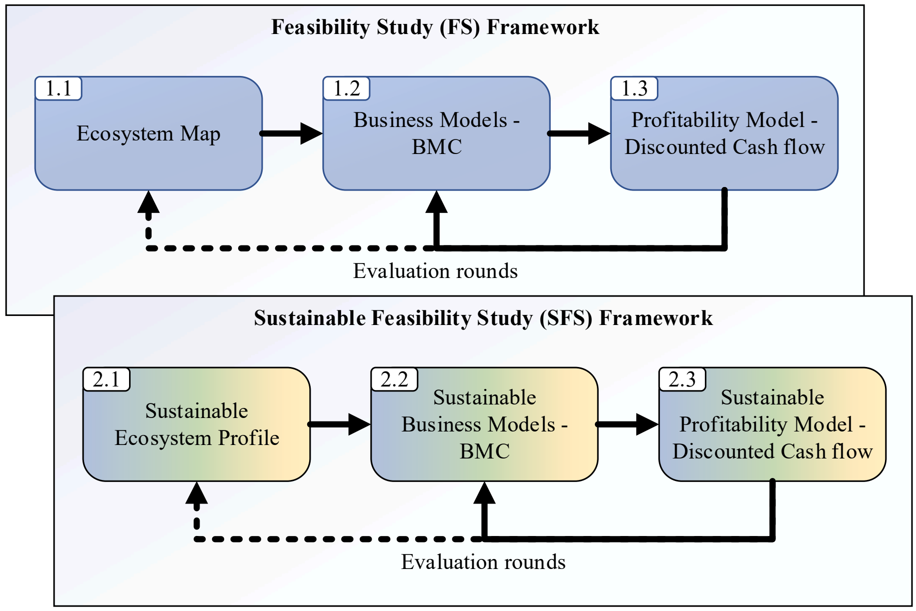

Fig. 7. SFS framework.

driven actors to form relationships and collaborate. The actors can no longer rely only on their own knowledge and skills in the competitive markets. This has created a need to understand ecosystems to be able to utilize synergies and monitor both rivals and partners (Basole, 2014).

The sustainable ecosystem profile (SEP) tries to meet these challenges. The SEP simulates the relationships and structure of an ecosystem and gives data-based insights into the ecosystem under review. The SEP can be used for research and management purposes as well as for understanding and managing ecosystems. The SEP includes three phases (Fig. 8): core, map, and information. In the core phase, the value proposition is created, and the core companies are identified. In the map phase, the related companies are explored, and relationships are visualized. In the information phase, the additional data to be collected is defined and the selected data is collected. The information phase differentiates the ecosystem profile from the ecosystem map. The sustainability perspective can be included in the ecosystem map, for example, by mapping industrial by-products, re-use, recycling, and/or energy recovery streams.

Fig. 9 shows an example of an ecosystem map where the core companies are represented along with two levels of related companies. Level 1 related companies have a direct and level 2 related companies an indirect relationship with the main core company (the biggest actor). The core companies are illustrated in bigger size and the same color, while the level 1 companies are slightly smaller and colored similar to each other. The level 2 related companies are the smallest in size, and they could be colored similar to each other or use a different color if necessary for the sake of clarity. The arrows represent both links and activities, and therefore the relationships between the actors, depending on the selected value proposition and perspective. The link is the transfer across actors, and activities are the discrete actions for the value proposition (Adner, 2017).

After visualizing the relationships and creating the ecosystem map, the data to be collected needs to be defined. Ylönen et al. (2021) have determined information that could be collected based on Kocsis's (2006, p. 6) book and an article by Mannens et al. (2013). Information the SEP could contain includes the products and/or services, financial status of the company, company size, balance sheet, key figures, subsidiaries, company structures, key partners, relationships with other actors, key

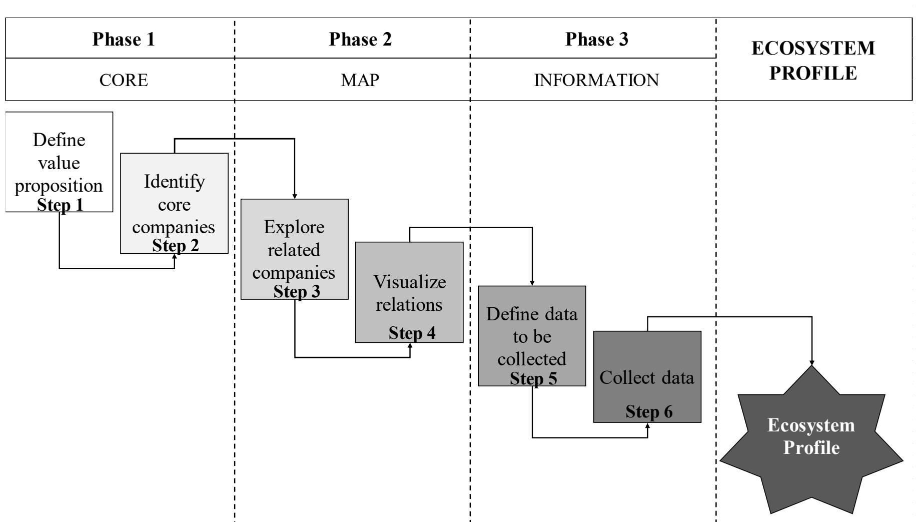

Fig. 8. The SEP creation process (Ylönen et al., 2021).

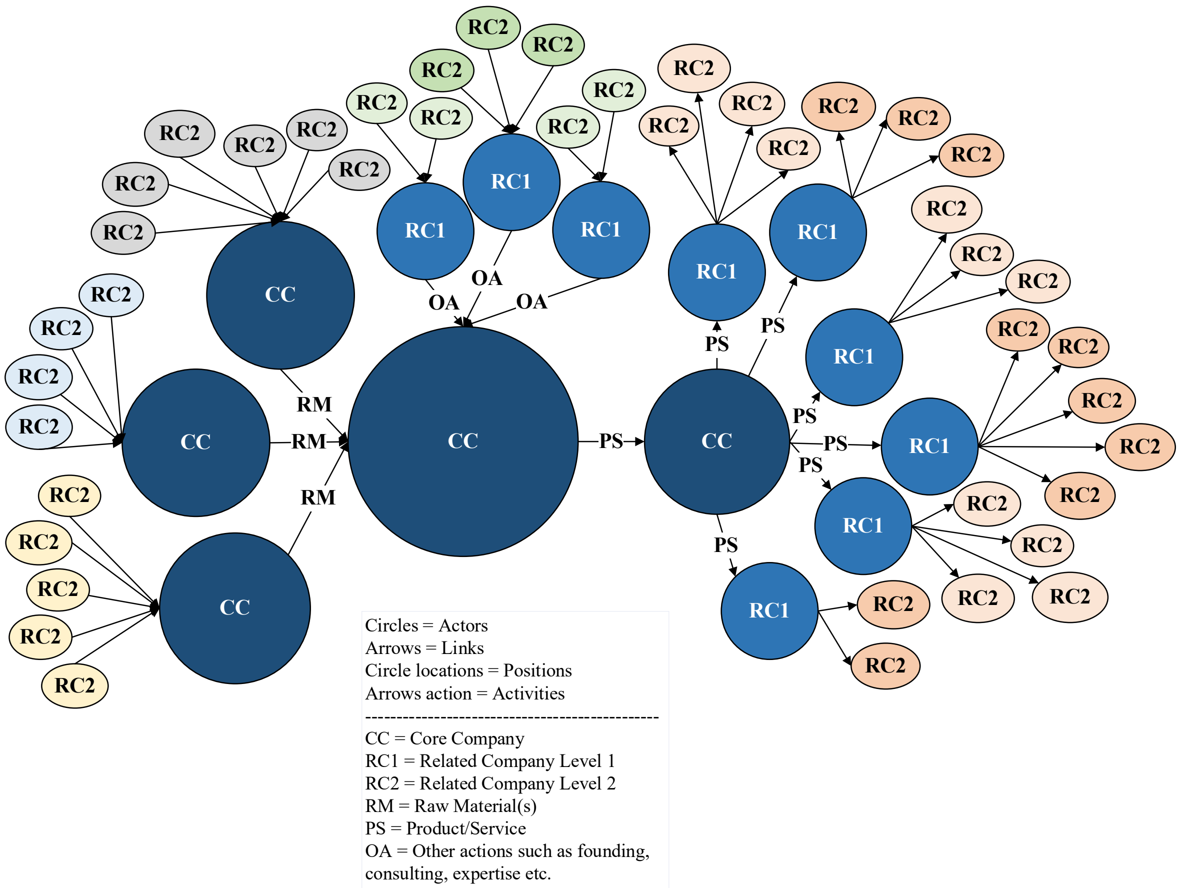

Fig. 9. Ecosystem map example.

customers, how the company reports itself (stock releases, news on company webpage, and other publications), and what is said about the company. According to Mannens et al. (2013), a user profile is formed of three categories of information: dynamic information, static information, and the social graph. Similarly to the user profile, the ecosystem information elements can be divided into these three categories: example company size is static information, stock releases are dynamic information, and customers are the social graph.

5.3. Sustainable business model canvas

According to Osterwalder et al. (2010), a business model canvas is a good tool for understanding the business model in a straightforward, structured way, and it can be applied to many different business model scenarios to illustrate the differences. It provides a comprehensive view of a business model in a single figure, and it is widely known and used both in industry and academia. The BMC can be used on many accuracy levels, from a detailed business model implementation level to a rougher business model sketch. The original BMC is good, but it has a few shortcomings, such as lacking a sustainability perspective. There is no environmental or social layer in the original BMC. To fix this deficiency in particular, the sustainable business model canvas (SBMC) was developed (Fig. 10). The SBMC was created based on multiple literature reviews of current BMC variations (see e.g. Cardeal et al., 2020; Foxon et al., 2015; Joyce and Paquin, 2016) and its suitability for P2X investment projects.

The SBMC has nine building blocks similar to the business model canvas of Osterwalder et al. (2010). However, the SBMC has all three dimensions of sustainability included: economical (blue), environmental (green), and social (yellow). All blocks have color-coded assistance questions to help fill out the figure and evoke ideas. The aim is to have a comprehensive and holistic understanding of the company's business model(s). The SBMC is recommended to be filled out after the SEP since ecosystem understanding should also be applied to the SBMC. The SEP and SBMC should not be thought of as separate tools but as a continuum.

In the SBMC, the nine blocks cover key values, resources, organization and activities, partnership, channels and distribution, customers, after the sales, costs and impacts, and revenues and benefits. **Key Values** describe the main value of the product and/or service, the functional unit, functional value, and the company's mission for creating benefit for its stakeholders and the society more broadly. **Resources** describe key resources for the key values, key materials for the functional unit and value, and the employee's role as a core organizational stakeholder. **Organization and activities** describe key activities for the key value, a form of ownership, core actions that the organization undertakes to create value, how sustainability has been considered in these actions, and the decision-making policy. **Partnerships** describe key partners, key suppliers, the supplier sustainability policy (SSP), and relationships being built with the suppliers and their local communities. **Channels and distribution** describe channels through which the customers want to be reached, how the customer is currently reached, the cost-efficiency of the channels, the carbon footprint of distribution, and the scale of outreach in the distribution. **Customers** describe customer segments, most important customers, the impact of the customer's partaking in the organization's key values, how the key values address the needs of the end-user contributing to their life quality, and the relationship that each of the customer segments expects the company to establish and maintain with them. **After the sales** describes the additional value to be delivered to the customer after purchasing the key values, the benefit from offering additional values, how sustainability has been considered in these additional values, what will happen after the customer chooses to end the utilization of the organization's key values, the potential impact of

Fig. 10. SBMC description.

key values on society as a whole, and the potential impact of an additional value on the customer. **Costs and impacts** describe the most important costs, the most expensive key resources and activities, the ecological costs of the organization's actions, and the social costs of an organization. **Revenues and benefits** describe overall revenue from each revenue stream, ecological value creation through environmental impact reductions, regenerative positive ecological value, and the positive social value-creating aspects of the organization's actions.

5.4. Sustainable evaluation of profitability

The assumption in the DCF is that all relevant effects of alternative investment projects are depicted by cash outflows and inflows and that other effects do not have to be taken into consideration. The second assumption using the DCF is that all cash flows can be estimated and allocated to defined periods of identical lengths (usually years) (Götze 2015, p. 47). One problem in terms of miscalculation is not calculating and considering all sustainability dimensions. That can happen especially if the focus is very economic-centric. The sustainable cash flow (SCF) is developed to improve cash flow calculation accuracy by including sustainability elements in the traditional cash flow and assisting the user with broader thinking (see Fig. 11).

The cash flow factors have been divided into dimensions of sustainability: economic (blue), environmental (green), and social (yellow). Each box is divided into revenue streams and costs. The SCF is calculated by adding up all the revenue streams and subtracting all the costs. The SCF is created by using the principles of life cycle cost (LCC), which offers practical methods for generating sustainable DCF models. Largely, the formulation principles of cash flows in sustainability investments are quite similar to those in traditional industrial investments. The major difference, however, is the scope and details which can be considered with different environmental and social benefits and costs of individual projects and ecosystems. Ecosystem and business model understanding and thinking should also be included in profitability calculations.

6. Discussion

Many hydrogen economy solutions have not yet met economic feasibility but have been realized as highly potential solutions in the future. The energy transition towards a sustainable energy future leads into remarkable investments into energy solutions, including hydrogen economy, and it is essential to evaluate the feasibility of various solutions in a sustainable manner. Different solutions are needed, but support from society is also required in order to make the transitions a reality. In the market, especially in the aviation, marine, and heavy-duty transportation sectors, there is a need for liquid fuels for a long time. With P2X technology, it is possible to create carbon-neutral liquid fuels to replace fossil fuels. It is noted that regulation (premium price) and demand will define the market price for P2X fuels rather than production costs. P2X fuels are likely to be included in the premium price, and demand will start to grow from 2030 onwards. The production costs will reduce after economies of scale can be achieved and the cost of renewable energy (electricity) decreases. The advantage of liquid e-fuel, like P2X, is that they can be easily and safely transported, distributed, and stored similarly to conventional fossil fuels. P2X fuels can soon become a serious competitor to biofuels and even to conventional fossil fuels over time. However, based on the early results of Laaksonen et al. (2021), P2X technologies can already meet economic feasibility (see Fig. 6) if P2X fuel production is considered in terms of the whole ecosystem around it and both sustainability and circular economy benefits are realized by all actors. Then, for example, the cost of P2X raw materials can be lower and infinite, while the raw material provider

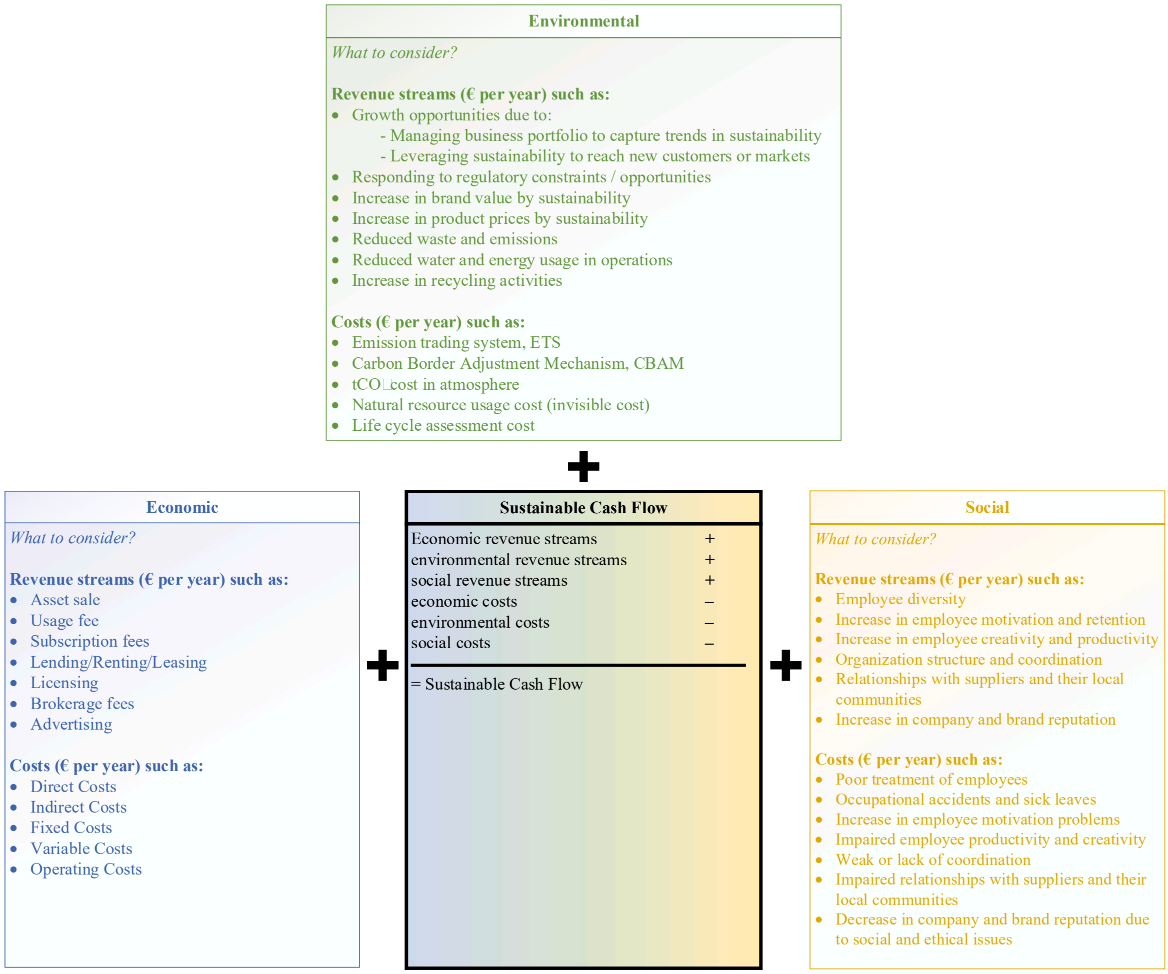

Fig. 11. SCF description.

benefits from utilizing their excess materials. The research of Laaksonen et al. (2021) stated that in the JPP "base case", which was created based on the most realistic value presumptions, the investor IRR can be as high as 12% with safe margins over the one-variable change. The most significant cost factors are gasoline price, total investment, hydrogen price, and operation time. In the JPP scenario, the planned values include the subsidy of 40% (see Fig. 6), but it can be assumed that in the future the share of subsidy will decrease but O&M costs (2% & 3%) and the cost of electricity (40 €/MWh) will decrease due to economy of scale and due to increased wind power capacity, which makes these technologies even more feasible.

The SFS framework supports realizing and utilizing the benefits of sustainability and circular economy. The SFS framework also enables the evaluation of P2X projects beyond the economic perspective by considering all dimensions of sustainability: economic, environmental, and social, giving a more comprehensive representation of real feasibility. Furthermore, the SFS framework considers feasibility at the ecosystem, business, and profitability levels, which makes it one of the most holistic feasibility frameworks in the current literature. By using the SFS framework, the ecosystem around P2X fuel production can be understood and utilized more efficiently, P2X fuel production as a business can be understood more deeply and broadly through which, for example, new strengths, weaknesses, opportunities, and threats can be identified, and the cash flows of P2X fuel production can be calculated and estimated more specifically. Over time, the legislation and regulations can affect and will be changed in a way that the environmental and social benefits increase and exceed the costs, and thus the SCF results are positive (see Fig. 11). For example, the costs of emissions can be increased due to regulations so that it is more cost-effective to invest into new green technology. In the end, the real feasibility of these energy investment projects depends on the aims of society.

7. Conclusions

To summarize this research, the primary outcomes are **1)** the new expanded SFS framework which covers the research gap over the lack of both feasibility studies for P2X investment projects and dimensions of sustainability in the business evaluation models. Furthermore, it was represented that **2)** the P2X technologies can already be economically feasible solutions if the investment is realized with ecosystem-wide collaboration and through circular economy. The SFS framework is designed to support the realization of these benefits and find the whole potential of the P2X investment projects. Huge investments are expected to happen in the near future to support the energy transition towards a sustainable energy future. It is necessary that the feasibility of these energy investments can be evaluated in a sustainable manner as, for example, the costs of emissions and other effects of regulations will play a more significant role in the calculation of SCF in the future. The SFS framework helps to understand and analyze the costs and benefits of investment projects, considering the investment projects' feasibility beyond the economic perspective by adding all three dimensions of sustainability: economic, environmental, and social.

The created SFS framework is developed for a small scale P2X pilot plant (JPP), but it is also scalable for a larger production facility, and it could be applied to other investment projects with relatively small changes or adjustments. In future research, the SBMC could be expanded from the business level into an ecosystem level canvas. Also, it could be researched whether it would be possible to add a dynamic description to the SBMC since, currently, various BMCs only consider a static description. In SCF, especially social costs and benefits may be difficult to identify and/or to estimate precise values. Therefore, further research could be done on how these values can be estimated or calculated more precisely. In this research, the new SFS framework was not utilized in P2X investment projects, and therefore the performance of the framework should be evaluated in later studies. The SFS framework could be applied to the JPP scenario to evaluate the performance of the framework utilization and whether the investor IRR of 12 percent would increase or decrease. The base presumption is that the SFS framework would increase the IRR in "green investments". It can be assumed that the environmental and social benefits exceed the costs in the future. In the end, the legislation and regulations can affect the way this happens, and environmental and social benefits gain weight when evaluating the feasibility of the investments.

CRediT authorship contribution statement

Jan Matinmikko: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Sini-Kaisu Kinnunen:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Tiina Sinkkonen:** Conceptualization, Writing – review & editing, Supervision, Project administration. **Timo Kärri:** Conceptualization, Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. List of suppliers of full-scale commercial technologies with specifications

Technology	Supplier	Technology type
Electrolysis	Cummins	Alkaline, PEM
	Green Hydrogen Systems	Alkaline
	Hydrogen Pro	Alkaline
	ITM Power	PEM
	McPhy	Alkaline
	NEL Hydrogen	Alkaline, PEM
	Siemens	PEM
	Sunfire	Alkaline, SOEC
CO_2 capture	Air Liquide Engineering & Construction	Cryogenic
	Aker Carbon Capture	Amine
	Carbon ReUse	Water
	GE Power	Amine, oxy-combustion
	Mitsubishi Heavy Industries	Amine
	Shell	Amine
	Toshiba Energy Systems & Solutions Corporation	Amine
MeOH synthesis	Air Liquide Engineering & Construction	Syngas/CO_2 to MeOH
	BSE Engineering	n.a.
	Carbon Recycle International	CO_2 to MeOH
	Johnson Matthey	Syngas to MeOH
	Mitsubishi Gas Chemical	Syngas to MeOH
Fuel synthesis	Chemieanlagenbau Chemnitz	MTG
	ExxonMobil	MTG
	Haldor Topsøe	MTG, syngas to gasoline
	Sunfire	Fischer-Tropsch

Appendix 2

Source data for the Laaksonen et al. (2021) profitability calculation model which combines all essential input data.

- Operation time (h/a)
- Annual production amounts of end products and by-products (from Aspen modelling)
- Production ratio %, availability
- Technical investment costs, including investments in hydrogen, CO_2, MeOH and MTG syntheses, auxiliary systems, electricity connection fees, infrastructure (roads etc.), buildings, engineering, interest and expenses during construction, bank's fees, land lease before the start-up, and permitting
- Reserve (%)
- Working capital addition (cash reserve)
- Financing, including investment subsidy (%) (TEM), debt (%), equity (%)
- Selling prices (€/t) for end products and by-products

- Costs and expenses during operation, including land lease, operation costs as percentage of actual revenue, maintenance costs as percentage of technical investment, electricity consumption and price, steam consumption and price, hydrogen consumption and price, carbon dioxide consumption and price, real estate tax, insurance costs, administration costs (percentage of actual revenue)
- Other source data, such as rate of inflation, income tax %, number of debt amortization, debt rate, straight-line depreciation (years), residual value, cost of equity and change % of WACC (weighted average cost of capital).

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