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Financing Structures of First-of-a-Kind (FOAK) Climate Projects

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Abstract

Climate hardware startups employ emerging climate technologies and drive economic growth. However, they often face funding gaps when establishing commercial viability, especially during the deployment of a first-of-a-kind commercial scale plant (FOAK). There has been growing discussion around FOAK financing and how to efficiently scale novel climate technologies. However, there is a lack of academic research on the topic. This thesis seeks to fill the literature gap, aiming to understand what conditions contribute to the development of successful FOAK financing structures. The thesis employs a multi-method qualitative study comprising of 21 semi-structured interviews and a multiple-case study involving six startups that have successfully closed funding for a FOAK plant in the Nordics. The results show that FOAK financing structures are diversified and no financing element is sufficient on its own to fully fund the plant, highlighting the need for different capital providers. The primary financing challenge centers around the risk-return ratio of FOAK projects. Financiers vary in their risk aversion, perceiving market and technology risk as the largest. Startups use different strategies to fund the FOAK, some through commercial validation and others through technological demonstration. Private senior loan recipients make FOAKs 'bankable' through public support, guarantees (which are necessary but not sufficient on their own for securing the loan), collateral and existing capital stack. Public support is a necessary condition for private investment in all cases, yet not sufficient on its own to make the plant fully funded. The risk-taking capacity of private investors alone appears inadequate to scale climate technologies at the pace needed to meet targets, highlighting the critical role of public funding. The findings align with existing body of research on financing green SMEs, suggesting that both diverse set of financiers and patient capital is needed. The critical question remains on how to de-risk and mobilize private capital to close funding gaps. The empirical part of the study identifies de-risking strategies that current actors have employed. Finally, the study introduces a simple model of FOAK financing, aiming to explain the FOAK fundraising process, including the internal and external factors influencing it.

Keywords FOAK, first-of-a-kind, climate tech, clean tech, startup financing, financing structure, capex-intensive, plant

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Tiivistelmä

Capex-intensiiviset ilmastostartupit skaalaavat uusia teknologioita ja edistävät talouskasvua. Ne kohtaavat rahoituskapeikkoja etenkin ensimmäisen kaupallisen mittakaavan laitoksen (FOAK) valmistelun aikana. FOAK-rahoituksesta on käyty kasvavaa keskustelua, mutta aiheesta on vain vähän akateemista tutkimusta. Tämä diplomityö pyrkii täyttämään tutkimusaukon ja sen tavoitteena on ymmärtää, mitkä tekijät edesauttavat onnistuneiden FOAK-rahoitusrakenteiden kehittymistä. Työ hyödyntää monimenetelmällistä laadullista tutkimusta, johon kuuluu 21 puolistrukturoitua haastattelua sekä monitapatutkimus kuudesta startupista, jotka ovat onnistuneesti keränneet rahoituksen FOAK-laitokselleen Pohjoismaissa. Tulokset osoittavat, että FOAK-rahoitusrakenteet ovat monimuotoisia, eikä mikään rahoituskomponentti yksinään riitä kattamaan laitoksen rahoitustarvetta, korostaen erilaisten rahoitusmuotojen tarvetta. Päärahoitushaaste liittyy FOAK-projektien riski-tuottosuhteeseen. Rahoittajat eroavat riskinottohalukkuudeltaan, pitäen markkinaan ja teknologiaan liittyviä riskejä suurimpina. Startupit hyödyntävät erilaisia strategioita saadakseen rahoituspaketin kasaan, osa kaupallisen validoinnin kautta sekä osa teknologian demonstraation avulla. Pankkilainojen saajat mahdollistavat lainarahoituksen julkisen tuen, takausinstrumenttien (jotka ovat välttämättömiä mutta ei riittäviä seniorilainan saamiseksi), vakuuksien ja olemassa olevien rahoittajien avulla. Julkinen tuki on välttämätön ehto yksityiselle investoinnille kaikissa tapauksissa, mutta se ei yksinään riitä täyttämään laitoksen rahoitustarvetta. Yksityisten rahoittajien riskinottokyky yksinään vaikuttaa riittämättömältä ilmastoteknologioiden skaalaamiseen tarvittavassa tahdissa, korostaen julkisen rahoituksen roolia. Löydökset tukevat olemassa olevaa kirjallisuutta vihreiden PK-yritysten rahoittamisesta, jotka korostavat monimuotoisen ja kärsivällisen pääoman tarvetta. Tärkeä kysymys on, miten FOAK-rahoitukseen liittyviä riskejä voidaan vähentää ja kuinka mobilisoida yksityistä pääomaa rahoituskapeikkojen kuromiseksi. Tutkimuksen empiirinen osa tunnistaa joitakin käytettyjä riskiä vähentäviä strategioita. Lopuksi tutkimus esittelee yksinkertaisen mallin, joka havainnollistaa FOAK-rahoitusprosessin, sekä siihen vaikuttavat sisäiset ja ulkoiset tekijät.

Avainsanat FOAK, first-of-a-kind, ilmastoteknologia, päästövähennys, kasvurahoitus, PK-yritys, tuotantolaitos

Contents

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Espoo 17.1.2025
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1 Introduction

1.1 Background and motivation

"Climate tech is not an app"
- Mala Valroy, Industrifonden

Reducing emissions is essential for both the environment and for sustaining economic growth. The Paris Agreement commits countries to limit global warming below 2.0°C by 2050 (UNFCCC, 2015). Moreover, recent research suggests that the economic harm caused by climate change is up to five times greater than previously assumed (Bilal & Känzig, 2024). In order to achieve emission reductions, there is an increasing demand for accelerating the financing of emerging climate technologies. According to forecasts from the International Energy Agency (IEA), up to 35% of the global emission reductions needed by 2050 will depend on the deployment of these technologies (IEA, 2023).

Startups that develop green technologies have an instrumental role in tackling climate change (Noailly & Smeets, 2015). Capex-intensive green investments – such as industrial plant investments – can be significant drivers of economic growth. According to Finnish Government (2023), the current governmental program prioritizes the development of large industrial investments, including climate tech investments.

However, many large-scale climate investments face a scarce availability of capital when establishing commercial viability. Bosio et al. (2024) find limited external financing as one of the largest bottlenecks for early-stage climate tech ventures. Funding gaps are often seen in the stage where first commercial plant is built. A FOAK (first-of-a-kind) project refers to the first large-scale deployment of a new technology, aimed at demonstrating its feasibility for commercial use. Funding gaps at this stage have been characterized as the 'missing middle' or the 'valley of death' of financing capital extensive business ventures, such as climate and deep tech startups (Arora et al., 2024; Mittelmeijer et al., 2024).

Since startups lack internal funds and do not suit the preferences of risk-averse project or debt financiers, venture capital becomes the primary mechanism for their commercialization (Nanda & Ghosh, 2014). However, from the investor's perspective, financing climate hardware projects presents a significant challenge, as these projects require large amounts of capital, have higher levels of risk as well as a lower probability in scaling up and successful exits (Cumming et al., 2016; Dalla Fontana & Nanda, 2023).

Existing literature suggests that private investors' often prefer asset-light industries over asset-heavy industries (Libert et al., 2016). O'Reilly (2023) argues that asset-light climate software startups have better access to early-stage capital compared to asset-heavy climate hardware startups. Similarly, Finnish Industry Investment (2024) provides evidence that software-based climate tech ventures raise funds faster in the first funding round than capital intensive climate hardware ventures, who are lagging behind.

Discussion around financing emerging climate technologies – such as those deployed at first-of-a-kind plants – has gained momentum, with a focus on the need for a diverse range of financiers (Nikkilä, 2024; Pratty, 2024a; Wharton et al., 2024). The prevailing argument suggests that an optimal FOAK financing structure has a balanced combination of different types of capital, such as equity, debt, quasi-equity and non-dilutive grants. Some argue that optimal FOAK financing structure is composed of equal amounts of debt, grants and equity (Pratty, 2024a), while alternative models advocate for a 50% equity and 50% grant structure, with the possibility of incorporating up to 30% debt if offtake agreements are in place (Reem, 2023). Offtake is an agreement where one participant ('the Offtaker') buys all or some portion of the output of a given plant (Thomson Reuters, 2024), providing a guarantee of future revenue. Offtake agreements are frequently seen critical in securing the confidence of potential financiers (Pratty, 2024b; Reem, 2023). Large-scale offtake agreements can ensure high upfront investment repayment (Climate Brick, 2024), de-risking FOAK projects.

Climate tech saw a surge in VC investment in the late 2000s, a period denoted as 'clean tech 1.0' (Gaddy et al., 2017). The solutions financed during this period were mainly centered around energy generation (Kanoff et al., 2023a). Several of the technologies that were in focus during the first wave of climate tech financing – such as wind energy – have achieved commercial viability due to technological advancements, lower costs and supportive policies (Kanoff et al., 2023a). This thesis examines the conditions that contribute to the development of successful FOAK financing structures. By doing so, it intends to understand how finance can help scale first-of-a-kind climate projects. The study envisions that similar to wind energy, the financing of FOAKs could accelerate the innovation cycle, ultimately allowing FOAK projects to reach widespread adoption.

1.2 Research problem and objectives

This thesis studies the financing structures of first-of-a-kind (FOAK) climate projects. The thesis takes the view of both the startups and the different types of FOAK financiers, i.e., equity, debt and grant providers. Main research question, sub-questions and objectives are presented in Table 1.

Table 1: Research questions and corresponding objectives

Research question	**Objective**
What conditions contribute to the development of successful FOAK financing structures?	To identify conditions that can be applied to future financial structuring
Sub-question	**Objective**
What FOAK financing structures have been used in the past?	To create an inventory of different types of FOAK financing structures and identify successful configurations or 'FOAK archetypes'
What challenges related to FOAK financing structures have emerged in the past?	To identify historical challenges, analyze root causes and develop mitigation strategies
How can a climate tech startup increase the investment readiness of its FOAK plant?	To understand ways to catalyze and de-risk FOAK financing
What is the role of each FOAK financier?	To explore current roles, possibilities and limitations of different capital providers

1.3 Methodology

The study has two main components: a theoretical section consisting of a comprehensive literature review, and an empirical section consisting of semi-structured interviews and a multiple-case study. Sections were partly carried out simultaneously to provide a more thorough understanding of FOAK financing and to ensure that the emerging theory aligned with both the data and the existing literature on climate tech financing. The literature review identified gaps in the existing research and established a foundation for the study. Literature review not only provides contextual grounding for the research on the financing of climate tech ventures, but also ensures alignment with existing knowledge while addressing gaps in prior studies (Webster & Watson, 2002).

The empirical section adopts a multi-method qualitative approach, drawing on Gioia et al. (2013) and Eisenhardt (1989). The multi-method approach ensures a more holistic understanding of FOAK financing, as the second qualitative study builds on the insights of the first study, providing a means to test the validity of proposed relationships. The idea behind the multi-method approach is that the Gioia method is used to explore how people interpret FOAK financing, while the Eisenhardt method focuses on understanding the events themselves, i.e., FOAK financing structures. This approach aims for greater objectivity by prioritizing concrete occurrences over subjective interpretations, which can introduce bias (Eisenhardt, 1989). The multi-method approach was seen as most fitting due to the Gioia method's capacity to provide both depth and structure for inductive coding and theme development, given the scarcity of existing research on FOAK financing. A case study utilizes a configurational approach, which refers to a way of analyzing FOAK financing structures by examining how specific combinations of financing elements interact to produce an outcome, successfully closing FOAK financing. Under the assumption that all studied cases represent a sample of successful financing structures as all of the examined startups have fully funded their FOAK plant, Eisenhardt (1989) methodology offers robust tools for cross-case analysis, facilitating the identification of consistent patterns and themes behind each financing structure. Furthermore, the Eisenhardt method complements configurational approach by enabling systemic multiple case analysis, facilitating the identification of patterns and relationships across cases while maintaining the context of each individual FOAK case.

The first empirical part of the thesis is a qualitative study consisting of semi-structured interviews. Following grounded theory (Corbin et al., 1990), the interviews began with a broad objective to understand key constructs related to FOAK financing. Using semi-structured interviews allowed respondents to freely express their views on FOAK financing. Following Gioia et al. (2013), data analysis was carried out simultaneously with data collection, as interviews were transcribed, coded and iterated using Atlas.ti® software. This process resulted in three overarching dimensions: FOAK capital stack, perceived FOAK financing challenges and perceived FOAK financing opportunities.

The second empirical part of thesis consists of a multiple case study following Eisenhardt (1989). Case studies on different FOAK financing structures provide contextual depth to the qualitative analysis as they allow local contextualization (Miles & Huberman, 1994), and analysis is performed within and across cases to allow identification of broader generalizations (Miles & Huberman, 1990; Stake, 1995; Yin, 2003). Data collection and analysis was carried out simultaneously. The analysis in the second qualitative study builds on the first qualitative study by focusing on the research question: *What conditions contribute to the development of successful financing structures of FOAK projects?* The interviews conducted in the first qualitative study were the primary source for identifying the conditions – elements in the financing structures – that contribute to the development of successful FOAK financing structures. In addition, existing literature provided additional context. The identified conditions guided the case analysis. Several tactics were employed to group the cases by different variables until consistent patterns and themes emerged from the data. The case analysis allowed the emergence of necessary and sufficient conditions for FOAK financing structures, as well as distinct configurations, 'FOAK archetypes', that employed certain strategies to successfully close funding for their FOAK.

Thesis as a whole relies on triangulation. Triangulation is broader in the kinds of methods that are combined (Flick, 2018, p. 2). Triangulation enables the synthesis of diverse data types, using the strengths and mitigating the limitations of each methodological approach (Jick, 1979; Webb et al., 1966). Several methods of data collection are used to facilitate diverse opinions, mitigate limitations of supplement data gathering methods and to enhance the credibility of the study through triangulation (Saldana, 2011, p. 76). For example, the case analysis utilizes both primary (interviews with startups and capital providers) and secondary data (public information).

1.4 Structure of the thesis

This thesis is structured as follows. Section 2 starts by exploring financing development of climate tech and connecting existing literature to the current FOAK financing landscape. Literature review as a whole covers relevant literature on climate tech financing. Section 3 covers the first qualitative part of the study, semi-structured interviews with both FOAK financiers and startups. The second empirical part of the study, multiple case study, is covered in Section 4. Finally, discussion in terms of the whole thesis is presented in Section 5, including the proposed model on FOAK financing (Section 5.1), comparison and discussion of the results with previous studies (Section 5.2), limitations of the study (Section 5.3) and avenues for further research (Section 5.4). Thesis structure is illustrated in Figure 1.

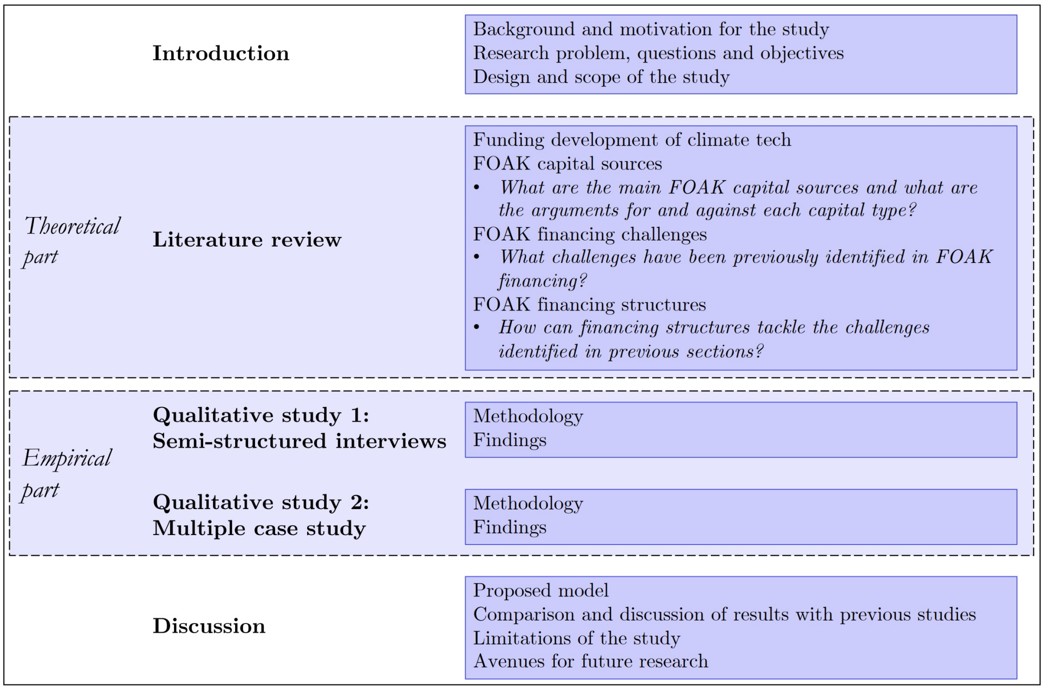


Figure 1: Thesis structure

1.5 Key concepts

In this thesis, the key concepts are defined as following:

1.5.1 First-of-a-kind (FOAK)

First-of-a-kind (FOAK) is the first commercially-relevant scale facility for a given climate technology. FOAK involves novelty in the form of a new technology or application. The technological readiness level (TRL) of a FOAK is usually 8 (out of 9, the system is "complete and qualified") and it has capital requirements of around EUR 10-100m (European Commission, 2024; Finnish Industry Investment, 2024). However, TRL of a plant may vary depending on the specific processes involved, and different sections of the plant could exhibit different TRL levels, including those lower than TRL 8. The concept of FOAK is relatively new and the definition varies by source. Identified aspects that affect the definition include:

1. *Technological innovation*: How novel is the technology? Is it protected by patents? Does the novelty stem from an innovative business model rather than from the technology itself? Does the plant employ a completely new technology or does the innovation rise from combining old technologies in a new way?
2. *Stage/scale*: In which stage of the commercialization is plant a FOAK – what is commercial scale? Does it depend on the profitability of the project? The commercialization process might include several plants, such as large-scale pilots, early demonstrations, late demonstrations or early deployments.
3. *Geography*: Is it a first of its kind in a certain geographic area?

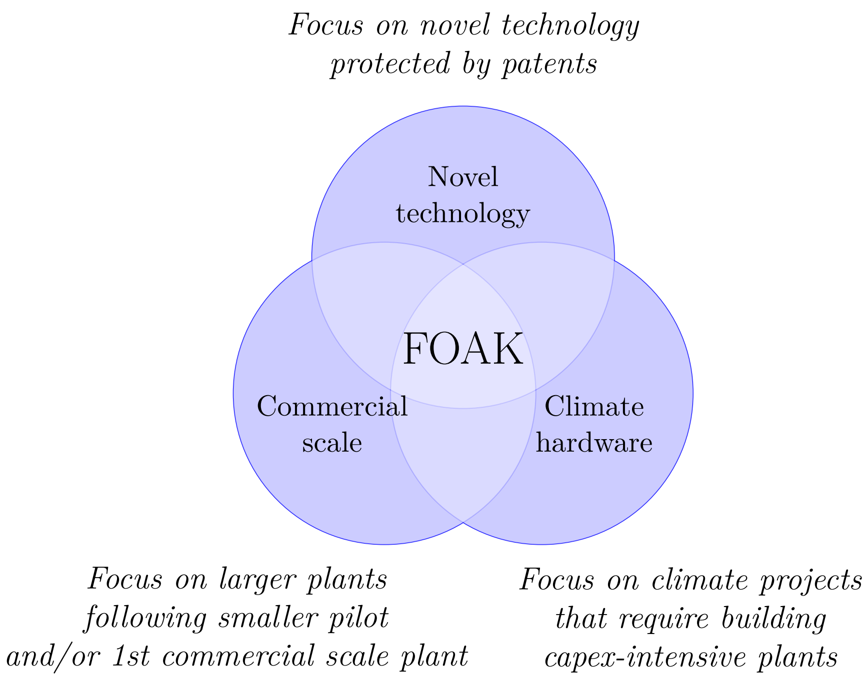


Figure 2: Definition of FOAK in this study

In terms of technological innovation, this thesis assumes that FOAKs include some sort of novelty in their process, demonstrated by IPs. In terms of scaling step, this thesis defines FOAK as the first larger scale plant executed in commercially relevant scale, that usually follows smaller sub-scale pilots/demonstrations. FOAK projects may not be cash-flow-positive over the life-cycle. Figure 3 illustrates the focus of the study in terms of scaling step.

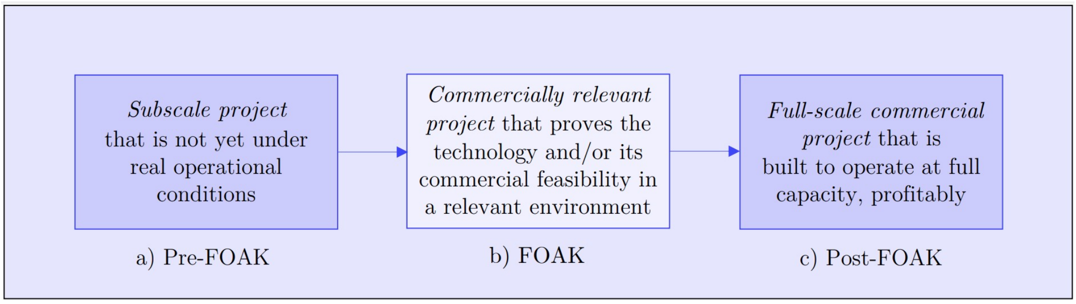


Figure 3: Definition of FOAK in this study in terms of scaling step

During the writing process it was noted that FOAK definitions vary by source, contributing to uncertainty surrounding the concept. For example, FOAK can be the first commercial project, yet different from the demonstration project, which is done "in the relevant environment, at the smallest scale needed to prove the technology works at scale", where at scale is the "size the technology is intended to be ultimately commercialized at" (Khatcherian, 2022, p. 12). Therefore, Khatcherian (2022) defines that FOAK does not follow a smaller pilot, but a demonstration project. On the other hand, Fab (2024) does not differentiate demonstration projects as separate, as according to the author, FOAK follows a smaller pilot plant. Further, OCED (2024) include large scale pilots in the FOAK definition. It should be noted that depending on the technology and startup preferences, some startups might also skip certain scaling steps, or have multiple similar plants within the same 'scaling phase'. All the case studies examined in this thesis involve what the participating companies describe as their first commercially relevant plant.

1.5.2 Climate technology (climate tech)

Climate technologies "reduce greenhouse gases and ease adaptation to the adverse effects of climate change" (UNFCCC, 2023).

Technology is “a piece of equipment, technique, practical knowledge or skills for performing a particular activity” (Metz et al., 2000). Following Muller (2003), three components of technology are defined as:

1. *Hardware*: defined as the tangible component
2. *Software*: defined as the processes related to the production and use of the hardware
3. *Orgware*: defined as an institutional framework or an organization that is involved in the adoption

This thesis focuses on startups that develop capex-intensive climate hardware, involving construction of plants.

1.5.3 Clean technology (clean tech)

This thesis treats the terms 'climate tech' and 'clean tech' as synonymous. During late 2000s, climate tech was often referred to as clean tech. Since then, it has been recognized as its own investment category or even an asset class. Mukherjee et al. (2024) highlight that different definitions of clean tech exist in current literature, including renewable energy and material-based views. This leads to, for example, some of the literature focusing entirely on renewable energy. When interpreting the findings of the literature review, it is important to acknowledge context-specificity: some conclusions applicable to renewable energy FOAKs may not hold true for other types of climate FOAK projects, and vice versa.

2 Literature review

2.1 Funding development of climate tech

This section looks at the funding development of climate tech. The section tries to answer the following questions: why did venture capital prove to be ineffective during the first wave of climate tech ('clean tech 1.0') and what the strategies could different actors adopt during the second wave of climate tech ('climate tech 2.0') to avoid repeating these failures.

Migendt (2017b) studies emergence of clean tech as an investment category. Clean tech as a VC category was established in the mid 2000s: investors were seeking new investment opportunities after the dotcom bubble, there was interest in reducing reliance on oil and public policy incentivized VC investments to environmentally friendly assets. According to the author, the term 'clean tech' was most used in the media in 2009. Foreshadowing the peak of clean tech bubble in 2007, John Doerr, a partner at the venture capital firm called Kleiner Perkins, hosted a TED talk called 'Salvation (and profit) in green tech' (Doerr, 2007). In his 2007 talk, Doerr stated:

> *Well, I'll tell you what. Green technologies – going green – is bigger than the Internet. It could be the biggest economic opportunity of the 21st century. Moreover, if we succeed, it's going to be the most important transformation for life on the planet since, as Bill Joy says, we went from methane to oxygen in the atmosphere. (Doerr, 2007)*

Ten years after Doerr's TED talk, Kleiner Perkins began separating its clean tech investing from the rest of its portfolio due to several failed clean tech investments (Frick, 2017). Kleiner Perkins now publicly states that according to their current investment thesis, venture capital isn't suitable for clean tech due to its infrastructure needs and long development cycles (Kleiner Perkins, 2024).

Climate tech saw a surge in VC investment in the late 2000s, a period denoted as 'clean tech 1.0'. According to Gaddy et al. (2017), VCs spent over USD 25bn in clean tech funding between 2006 and 2011. The first wave of clean tech ended as the bubble burst in 2011. Less than half of the capital invested by VC firms was recovered after collapse, leading to a significant decline in clean tech funding. The authors note that as funding volumes recovered after the financial crisis of 2008, the clean tech sector was left out.

Reflections were made after the burst of the bubble. Some saw the troubles around clean tech to be centered around capital intensity. Knuth (2018) point out that at the time, clean tech supporters saw software-centric clean tech as a potential investment area:

> *Venture capital works much better for software-centric clean tech, or the 'clean-web,' which includes less capital-intensive technologies occupying the intersection between information technologies [...] and clean tech. (Luce & Steel, 2015, p. 188)*

Venture capitalists also started to understand the government's role. Governmental support can often present a 'make or break' -moment for many startups. In some cases, this support can even prevent competing entrepreneurs, alternative technological paths and new business models from emerging (Hargadon & Kenny, 2012). In 2010, Stephan Dolezalek, then Partner of VantagePoint Venture Partners talked about the role of the government in scaling clean energies:

> *We learned that we had to be as good as the defense contracting firms at understanding the flow of dollars from government. If government was going to hand out money, we had to figure out how to get our fair share. (Hargadon & Kenny, 2012, p. 12)*

Why did VC fail during clean tech 1.0?

Less than half of the capital invested by VC firms was recovered after collapse of clean tech 1.0, following several failures among clean tech startups (Rotman, 2023). For example, the number of solar companies closing, filing for bankruptcy or being sold under unfavorable conditions in 2012 was about four times bigger than the year before (Gaddy et al., 2017). There are several possible explanations over why VC failed during the first wave of clean tech investment. There is also uncertainty on the effect of exogenous factors (Gaddy et al., 2017). In general, VCs are high-risk investors and many of their investments fail due to high technology risk (Nanda & Ghosh, 2014), which is also predominantly present in many clean tech investments. Moreover, research shows that 75% of all VC-backed startups fail (Blank, 2013). The following paragraphs present existing hypotheses around why VC failed during clean tech 1.0.

Clean tech does not fit the traditional VC model: During his TED talk in 2007, many of John Doerr's industry peers agreed that clean tech as an investment category offered lucrative possibilities for venture capitalists, and that clean technologies fitted well the traditional VC model (Gaddy et al., 2017). Ten years after Doerr's TED talk, Kleiner Perkins began separating its clean tech investing from the rest of its fund (Rotman, 2023). Kleiner Perkins, such as many other generalist VC funds, had underperformed due to several failed clean tech investments (Frick, 2017). Several authors have argued over clean tech and/or energy not fitting the VC model (Gaddy et al., 2017; Hargadon & Kenney, 2011; Knight, 2011; Lerner & Nanda, 2020; Nanda et al., 2015). Reasons include competitive commodity markets, harder/non-established exit mechanisms, regulatory and technological risks, high capital intensity, long development cycles, expensive scaling as well as long-term uncertainties related to clean technologies and their path to market. Furthermore, the authors highlight that clean energy sectors are characterized by poor exits, as large energy conglomerates have shown limited interest in buying these innovative startups. Hargadon and Kenney (2011) identify three key characteristics for technologies and markets where investments fit the VC model: large markets with ample growth potential, scalability of business models as well as potential for substantial and quick return through an exit. The authors argue that these characteristics do not generally hold in the context of clean technology market in the United States.

The Solyndra case demonstrates several key arguments over clean tech and/or energy not fitting the VC model. Caprotti (2017) investigates the success and failure of solar panel maker Solyndra. Solyndra required a long time to bring its cylindrical solar panels to market. VCs generally prefer investments with a 3-5 year horizon for returns, but Solyndra's development cycle exceeded that. Building and scaling solar panel plants was also highly capital intensive. Due to this, Solyndra attracted significant amounts of both private and public financing. Finally, Solyndra operated in competitive commodity markets. The authors highlight that Solyndra's alleged competitive advantage was the ability to produce high volumes of cylindrical thin-film modules more cost-efficiently than competitors. However, Solyndra faced intense competition from low-cost Chinese flat solar panel manufacturers that were further boosted by Chinese government subsidies.

Mistakenly applying software scaling strategies to hardware scaling: During the first clean tech wave, many venture capitalists had experience from the technology sectors which were fast to scale. As a result, they mistakenly tried to apply the same strategies to clean tech companies, even though these companies faced a different set challenges (Rotman, 2023). Ramana Nanda, Professor of Entrepreneurial Finance at Imperial College London, outlines the key lessons learned from clean tech 1.0:

> *[Talking about the difference between software and hardware VC scaling] I think the big lesson from clean tech 1.0 is that molecules don't work the same way as bytes. [...] We really don't know if something will work until we build that large demonstration plant that costs lots of money. (Rotman, 2023)*

Weak demand: van den Heuvel and Popp (2022) argue that weak demand was one factor behind VC's failure in clean energy. The authors provide evidence that venture capitalists adjust their behavior according to changes in expected future demand. As the governmental support in clean technologies declined post-bubble, venture capitalists reduced their investments as well.

Lack of product differentiation: van den Heuvel and Popp (2022) argue that clean energy startups have lower product differentiation, which leads them to have lower margins. This, in turn, makes them less likely to be 'home runs' for VCs, and the clean energy startups that are able to create products with higher product differentiation can find it easier to attract VC financing. In addition to lower product differentiation, the authors also point out that lack of network effects and IP makes it harder for these companies to maintain competitiveness. These characteristics prevent the formation of 'winner takes all' -markets. The authors also highlight that temporarily boosting market demand will not alter these fundamental market characteristics.

Financial constraints: van den Heuvel and Popp (2022) point out that while the capital intensity and financial constraints in general are often cited as main obstacles for access to capital, they do not seem to explain the failure of venture capital in clean energy. The authors note that software-based energy startups were also affected by the post-bubble effects, experiencing a decreased VC financing in the later stages of the first clean tech wave. The authors further highlight that, despite being a capital-intensive investment category, electric vehicles have successfully attracted investors in recent years. To further demonstrate that financial constraints are not behind failure of VC in clean energy, the authors suggest that if financial constraints were behind limited financing, the few funded high-quality capital-intensive startups should generate high returns. However, they find no evidence that venture capitalists in clean energy are missing out on profits, or as the authors say, 'leaving money on the table'.

Unoptimal financing structures: Some argue that during the first wave of clean tech, projects were funded with wrong type of capital, with large-scale infrastructure projects being backed solely by equity rather than more appropriate financing options, such as project financing (Pratty, 2024c). Investors can find it difficult to allocate large equity tickets for climate hardware startups due to comparably low valuations (Lechtenfeld et al., 2023). As number of investors increases, each individual is required to commit less capital, reducing their exposure to risk. Authors have also advocated for a collaborative approach involving different stakeholders (Gaddy et al., 2017; Pratty, 2024a; Rotman, 2023), ranging from corporations (Gaddy et al., 2017) to affluent individuals (Nanda, 2020). Some argue that climate tech requires use of 'patient capital' (D. Kenney, 2021; Nanda, 2020), such as government grants and impact-first investments. This is also referred to as 'catalytic capital' due to its ability to catalyze further funding (Y. Wang, 2024). Catalytic capital providers are driven by impact-first approach rather financial returns, enabling more patient and risk-tolerant funding. Patient investment approach is also well suited for FOAK projects (Nikkilä, 2024).

The current state of climate finance

Climate tech has regained significant amount of investment in recent years, with some naming this the second wave of climate tech, 'climate tech 2.0'. Record investments amounting to USD 37bn were seen towards climate tech in 2021 (Kanoff et al., 2023b). Conversation between Breakthrough Energy's founder Bill Gates and Executive Director Rodi Gudeiro in July 2024 reflects the current state of climate innovation:

> *Scaling means we will have to engage traditional finance. [...] We are talking about big pension funds and big sovereign funds coming in with substantial amounts of their assets. We'll be measured by scale. [...] The amount of emissions abated with our technologies so far is quite small; yet by 2040, it has to be absolutely gigantic. [...] [Scaling] will continue to be challenging. [...] We have to draw in others, different types of capital. When we started Breakthrough, the venture community did not want to do this; we are getting ready—this is the decade now when we get to start to scale. That is what we see for the next ten years. (Breakthrough Energy, 2024a)*

The conversation took place in Breakthrough Energy Summit 2024, where over 1,500 climate leaders gathered to discuss about the future of climate tech (Breakthrough Energy, 2024a), demonstrating a growing movement to scale climate technologies.

Lerner and Nanda (2020) study venture capitalists' role as innovation financiers, and suggest that specifically risks related to regulation, technology and market explain underperformed VC investments in hardware. The authors also discuss new approaches to managing innovative investments, such as in-house incubation. For example, Breakthrough Energy Ventures facilitates the collaboration of in-house scientists with traditional investors. The authors highlight that these new approaches may widen the scope of VC investment. However, the authors conclude that record on collaborative investments has been mixed: one analysis shows that between 1993 and 2013, CVCs lost 4 percent each year, while IVCs had annual returns of approximately 30 percent. However, the authors note collaborations to be beneficial if executed correctly, highlighting philanthropic organizations' role in financing early-stage R&D. The idea behind philanthropic involvement is the facilitation of private capital.

New developments have occurred since the first wave of climate tech. Kanoff et al. (2023a) compare the current landscape to clean tech 1.0 and identify distinct advantages in current climate, including the broader acceptance of climate change, critical mass of public and private climate pledges, increased regulatory support, increased climate tech demand from corporations and improved technology readiness and production costs. Lower price encourages wider adoption and boosts related software and service sectors that promote these technologies. Furthermore, van den Heuvel and Popp (2022) argue that the policy environment today is increasingly supportive compared to that in the past. Similarly, Rotman (2023) argue that market conditions for clean technology startups are significantly more favorable today than they were a decade ago. However, the authors also highlight that political shifts can significantly alter the operating environment, imposing political risks.

The urgency for climate solutions highlights the immediate need for capital deployment and the acceleration of innovation cycles. According to IEA (2023), in order to reach net zero by 2050, around 35 percent of greenhouse gas emissions reduction will come from technologies that are currently in demonstration or prototyping phases. These technologies are currently scaled up in FOAK climate projects, the topic of this study. Need for accelerated innovation cycles highlights the need for different sources of capital. EU's Sustainable Financial Disclosure Regulation requires funds to categorize themselves based on their environmental and social impact, where Article 9 funds aim to achieve significant sustainability outcomes as a primary objective. The regulation also requires other financial market participants, such as banks, to integrate sustainability dimensions in their processes (Scheitza & Busch, 2024). EU has set an ambitious target through the EU Green Deal to create a net-zero economy by 2050, highlighting need for technological investments (Calipel et al., 2024). Philanthropic actors, such as Breakthrough Energy, have emerged to scale climate projects, such as FOAKs (Breakthrough Energy, 2024b). Public and private lending institutions have increasingly taken larger shares of risk in FOAK projects. In addition, private debt markets have grown substantially, allowing higher risk taking from non-bank entities (Muminović, 2024). Furthermore, Rotman (2023) argue that the key difference today is that venture capitalists are no longer financing climate tech alone, as the pool of financiers willing to finance risky scale-ups is growing.

2.2 FOAK capital sources

This section aims to identify the primary FOAK capital sources, analyzing prior research on each capital provider's role in financing climate technologies.

Letout and Georgakaki (2024) discuss the financing of climate technologies, focusing on strategic net zero technologies. The authors find that globally venture capital investors are most common climate technology investor, followed by corporations (e.g., corporate venture capital) and investment managers/funds.

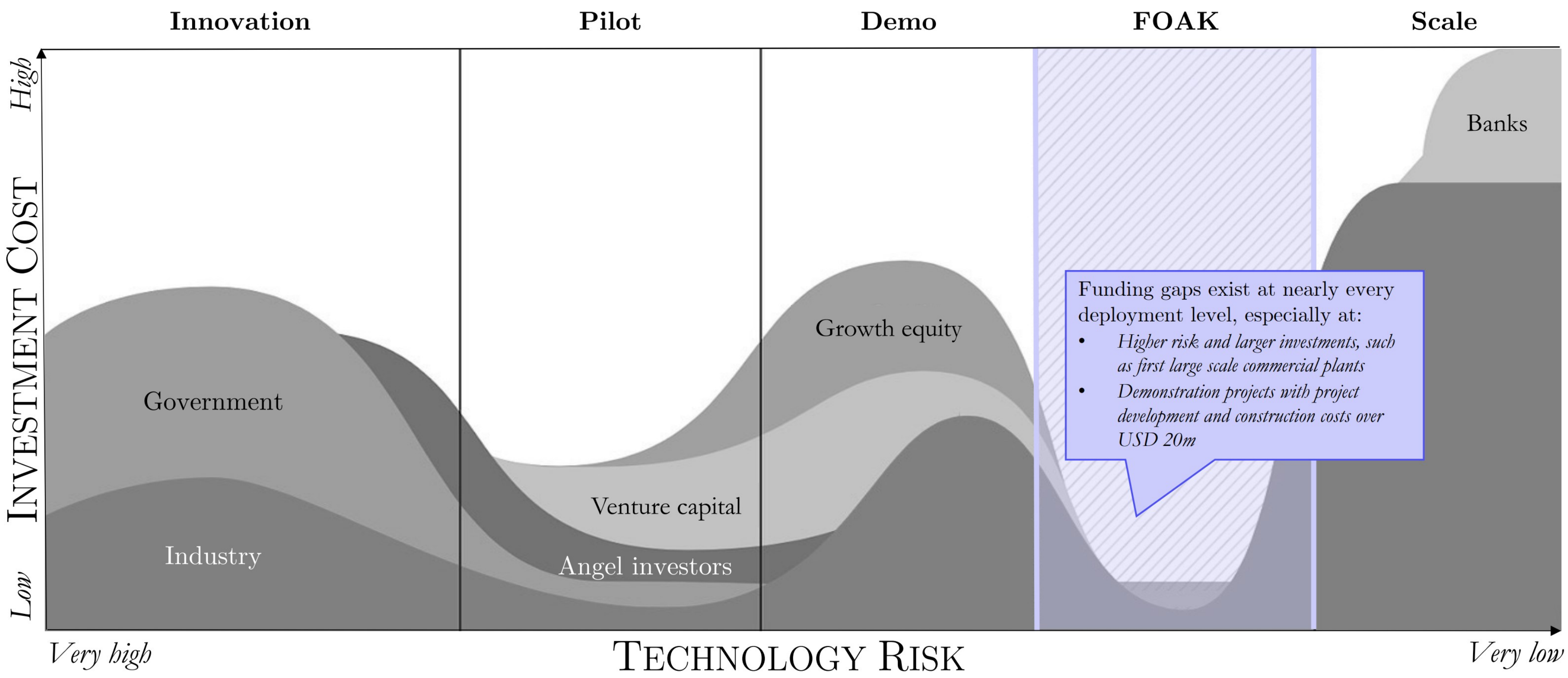
According to Letout and Georgakaki (2024), there has been an emergence of new types of climate tech investors and larger average contributions of several types of climate investors in the past decade. For example, the participation of investment managers/funds (e.g., public equity asset managers and family offices) has increased significantly since 2019. Authors provide evidence that governments have also increased their contributions since 2018, although government involvement is characterized by volatility, which is likely explained by certain large deals. Further, Owen et al. (2023) point out to the growth in alternative, non-bank finance for small and medium-sized enterprises that are fostering green innovation, including business angel networks, equity crowdfunding and larger implementations of public co-financing.

Selection of relevant journal articles for financing climate technology startups is presented in Table 2. Academic publications on FOAK financing were not identified during the literature screening process. Published research is focused on the financing of clean technologies, which includes most of the characteristics within the topic of the study. Focus of green entrepreneurial finance papers has been on private sector sources (Mukherjee et al., 2024), focusing on venture capital, suggesting that certain sources of capital are less researched. A significant portion of the research has also been conducted in the aftermath of the first wave of clean tech. This may result in some research focusing on the shortcomings of certain investor types, such as venture capitalists.

Several types of capital can be used to finance first-of-a-kind climate projects, with financiers locating to different stages of financing based on the risk and size of the project. Several funding gaps have been identified in the current climate technology investment ecosystem. Khatcherian (2022) highlight funding gaps especially for larger demonstration projects and first large scale commercial plants. Figure 4 illustrates the blend and availability of capital changes over time in the context of FOAK financing, based on Yeh (2024). The figure illustrates how the FOAK-stage is characterized by funding gaps from several different capital providers: the early stages of innovation are often funded by governments and VCs, while later stages, as technologies become less risky, suit bank financing. As a result, FOAK-stage remains a bottleneck for the startups. The figure illustrates how the availability of capital increases after the FOAK-stage as projects become repeatable and de-risked, making them eligible for project finance (Khatcherian, 2022; Yeh, 2024).

Table 2: Summary of key studies that focus on financing climate technologies

Authors	Year	Focus	Methods	Main findings
Cowling & Liu	2023	Cleantech startups' access to equity and debt finance	*Quantitative study* where authors use survey data from UK cleantech SMEs to study the relationship between clean tech firms and financiers	Clean tech startups have higher demand for external capital, which are not met by traditional capital providers, highlighting need for non-traditional financiers
Dalla Fontana and Nanda	2022	VCs and deeptech startups that develop net-zero innovations	*Qualitative study* where authors discuss existing literature related to venture capital's relationship with deeptech complemented by descriptive analysis of patent data	VC-backed firms are a small share of net-zero patents despite VC's focus patent-driven innovation, VC's have high barriers to investment in deep-tech startups
Gaddy et al.	2017	VC and cleantech	*Quantitative study* where authors analyze historical VC cleantech investments. The authors study investor risks, returns, risk-return profiles, exit outcomes and isolated cleantech sub-sector performances (cleantech software vs cleantech hardware)	VC is 'wrong model for energy innovation', hardware cleantech posed high risks and yielded low returns to VCs, cleantech software performed better than hardware, returning capital to early investors
Hegeman & Sørheim	2021	CVC and cleantech startups	*Qualitative study* where authors employ a multiple case study design focusing on 26 cases/CVCs	Heterogeneity within cleantech CVCs; small and medium corporations are active cleantech investors; CVCs motivations to invest vary
Islam et al.	2018	Grants and cleantech startups	*Quantitative study* where authors analyze the effect of US government research grants on the likelihood of receiving subsequent VC funding	Government grants serve as a positive signal to venture capitalists, improving chances of subsequent VC funding
Mukherjee et al.	2024	Finance for early-stage clean tech companies (Financing includes equity, debt and grants)	*Qualitative study* where authors conduct a systematic literature review on financing green early-stage SMEs	Cleantech characteristics such as capital intensity, long investment horizons and high level of innovation underline need for public financing instruments and policies to de-risk and mobilize private funds
Owen et al.	2023	Finance for early-stage clean tech companies (Financing includes equity, debt and grants)	*Qualitative study* where authors review SME's financing requirements, barriers of private investment and shortcomings of public policies	Cleantech SMEs face funding gaps, access to patient capital remains a barrier, holistic mix of SME green finance programs and instruments needed, non-traditional investors can address some of the challenges
Polzin et al.	2016	Institutional innovation intermediaries role in finance mobilization for cleantech	*Qualitative study* where authors employ a multiple case study design focusing on six cases/institutional innovation intermediaries	Institutional intermediaries act as innovation drivers, intermediaries' funding instruments are associated with positive impacts, yet impacts are context-specific and linked to the overall innovation system
van den Heuvel & Popp	2022	VC and governments in the context of clean energy	*Quantitative study* where authors test if changing expectations affect VC decisions through an event study around the failure of a comprehensive US climate bill in 2010. Authors also use descriptive statics to study clean energy startups	Lower demand and lower potential for returns make clean energy startups less attractive for VC, public investments can mobilize VC investment, stimulating demand offers better results than direct investments



Notes: while the figure establishes a difference between demonstration and FOAK stage, this thesis defines large scale demonstrations that companies describe as their first commercially viable scale plants as FOAKs. These projects experience similar funding gaps to larger FOAK plants and are included in the FOAK definition in several sources.

Figure 4: Conceptualization of an investment ecosystem for climate technologies. The figure illustrates the evolution of capital blends and access over time. The higher the stack is, the easier it is to access capital. Modified from Khatcherian (2022) and Yeh (2024)

2.2.1 Equity

Venture capital, VC, is the most common source of capital for climate tech (Cornelli et al., 2023) and key source of capital for commercialization of radical innovation (Nanda & Ghosh, 2014). In addition to capital, venture capitalists offer non-financial support, such as managerial expertise and networking opportunities (Mukherjee et al., 2024). Venture capitalists pursue a value-maximizing investment strategy, allocating capital to innovative companies that have patented intellectual property, allowing growth in emerging sectors (Akcigit et al., 2022). Venture capitalists can have varying effects on venture outcomes due to internal structures, investment rationale and capabilities (Wunder & Maula, 2024). While venture capitalists are the most common climate tech investors, several authors have pointed out the limitations of the VC model in terms of financing clean technologies (Bocken, 2015; Dalla Fontana & Nanda, 2023; M. Kenney, 2011; Nanda & Ghosh, 2014), with specific challenges comprising of high technology risks, high regulatory reliance, capital intensity and low scalability (Foxon & Pearson, 2008; Nanda & Ghosh, 2014; Polzin et al., 2016).

Independent venture capital, IVC, refers to organizations formed by general partners that raise capital, manage funds and follow a certain investment thesis. Some venture capital funds can have a thematic focus on climate tech, making them more relevant to startups that are building climate tech FOAKs. According to Randjelovic et al. (2003), regulatory push can influence investors to seek more environmentally and socially responsible funds. FOAK-specific funds are a rarity, yet some have been established in recent years.[1]

Nanda and Ghosh (2014) argue that a range of factors make clean technology startups more challenging for venture capitalists, including: capital intensity, no establishment of an exit mechanism as well as global commodities and policy risk. Further, Dalla Fontana and Nanda (2023) find that even though VC-backed firms have a higher likelihood of holding fundamental science patents, VC-backed firms represent only a small share of patents related to climate change mitigation, and that there is a smaller share of VC-backed deep tech firms today than before. The authors suggest that this is due to capital intensity, long time scale of experimentation cycles, low learning efficiency of laboratory experiments, need for talented human capital in deep tech translation and lower returns. Lerner and Nanda (2020) suggest that high regulative, technological and market risks could at least partly explain the poor performance of venture capital in capital-intensive investments as well as their reduced focus in non-software investments. For example, the authors highlight that accurately predicting the unit costs of large-scale energy storage technologies, such as those utilizing novel battery materials, is challenging even if they have been demonstrated at a laboratory scale. This uncertainty relating to unit costs relates to corresponding market demand, making future success hard to demand from the investor's

[1] For example, Trellis Climate

perspective. Marcus et al. (2013) study venture capitalists' role as a clean energy investor. The authors provide evidence that venture capitalists have been investing larger amounts of money over longer periods in the context of clean energy investments, which would imply that venture capitalists have adapted their investment processes to the needs of clean energy. However, the authors also point out that they have also been avoiding financing some segments, such as high risk production and manufacturing, and focused on financing software companies. Bianchini and Croce (2022) provide evidence that clean tech institutional venture capital investments are mainly driven by the extent of regulatory measures and market pull mechanisms, such as R&D grants. M. Kenney (2011) argues that there is no evidence that venture capital could not create value within green tech. The author points out that the key challenge is instead that venture capital is not structured to support large number of opportunities. The author believes that there will be adequate returns within green tech for VCs, however, they are unlikely to match some of the powerful feedback loops within information technology.

Bocken (2015) studies VC in the context of sustainable business, providing evidence that VCs provide support related to finances, triple bottom line and networks. They also find that VCs can, indeed, aid in the success of green business models and de-risk investments through co-investing. Dalla Fontana and Nanda (2023) discuss ways to increase venture capital's role in climate mitigation, including government's role in stimulating demand, supporting technical de-risking through financing and certification, as well as supporting emergence of new organizational and financing models. Petkova et al. (2014) find that reputable venture capital firms' share in clean energy investments is smaller due to substantial risk reduction strategies. The authors also find that the capital intensity of clean energy makes smaller-scale venture capital commitments inadequate. The authors highlight the importance of alternative capital sources to facilitate venture capital involvement. Further, Nanda (2020) argues on behalf of bringing larger amount of different investors that bring different incentives, funding models and risk-tolerance. The author points out that understanding how these can be best adapted is a promising area of further inquiry. Marcus et al. (2013) note that venture capitalists need to modify their investment patterns to accommodate clean tech investing. Nanda et al. (2015) discuss structural factors blocking venture capital involvement in renewable energy, highlighting the difficulty of exits. They propose larger and longer funds as one solution.

Corporate venture capital, CVC, refers to corporations investing their funds to startups. Corporate investors have structural differences in terms of their size, ownership and investment management (Hegeman & Sørheim, 2021). There is a trend of growing CVC investment in climate tech startups (Letout & Georgakaki, 2024; Surana et al., 2023). Letout and Georgakaki (2024) find that corporate investors focus most of their efforts in the later-stage investments. Hegeman and Sørheim (2021) investigate different CVC motivations for investing in clean energy technology startups, suggesting that there is heterogeneity within CVCs and the primary reason for investing is corporate greening as a way to maintain competitiveness. In an earlier study, Bansal and Roth (2000) find three distinct drivers for corporations promoting ecological responsiveness: legitimacy, strategic value captured from greening activities or ecological responsibility. Hockerts and Wüstenhagen (2010) find that new entrants exhibit a higher likelihood of pursuing sustainability-related opportunities in the early stages of an industry's transformation. The authors note that as a reaction to the activities of these new entrants, incumbents participate in corporate sustainable entrepreneurship activities, such as CVC. Corporate venture capital investors can select greener ventures than IVCs, driven by CVC investors with parent corporations active in green innovation (Wunder & Maula, 2024). CVCs can also engage in facilitation of post-investment innovation (Wunder & Maula, 2024). Letout and Georgakaki (2024) study the role of corporate investors in the financing of clean energy startups. The authors find that certain technology areas (e.g., energy storage, batteries and hydrogen) are advancing toward large-scale use and have broader industrial applications, helping corporations in their sustainable transition. As a result, these technology areas are associated with a positive impact of corporate financing. However, the authors note that corporate investment in EU-based firms is concentrated and not effective across all technology areas. Some authors argue that CVCs can provide patient capital as they are more inclined to make long-term investments and have greater patience due to strategic objectives; corporations can also use CVC as a form of research and development (Pillsbury Law, 2024). In certain cases, corporations can have experience of scaling new technologies (Rivera, 2024), which can benefit both the startup and other investors. Hegeman and Sørheim (2021) study CVC investments in cleantech startups and mention 'sharks dilemma', originally introduced by Katila et al. (2008), where startups face a choice between engaging with or walking away from corporations, as both choices have advantages (e.g., extensive resources) and disadvantages (e.g., risk of corporation turning into a competitor). Finally, Rivera (2024) argue that CVC investors can have an important role in shaping the narrative around emerging markets for FOAK technologies, as they use their previous knowledge from scaling similar technologies. The author emphasizes that, beyond technical support, corporations can also assist with fundraising by leveraging and sharing their networks with the startup.

Governmental venture capital, GVC, refers to a government-owned venture capital funds. GVC funds are typically created to help mobilize private investment. There is evidence suggesting that private capital providers – both equity and debt – are not willing to take the technology risk associated start-ups and scale-ups, highlighting the need for public money that can take on more risk (Quas et al., 2022), issue also evident in the financing of climate technologies (Lechtenfeld et al., 2023). GVCs can provide patient capital (Murray, 2020) to early-stage clean tech innovation (Owen et al., 2020). Further, Murray (2020, p. 6) argue that "state has responsibilities and goals for its VC actions that are far wider and, critically, over a longer time span than professional institutional investors". GVC organizations can de-risk and co-finance (Murray & Lingelbach, 2010) to encourage, upskill and develop nascent early-stage pre-commercialization cleantech ventures (Owen, 2023). Successful governmental venture capital initiatives have been highlighted in previous research (M. G. Colombo et al., 2016; Guerini & Quas, 2016). van den Heuvel and Popp (2022) argue that governments should bridge funding gaps that are a result from certain characteristics of clean energy, such as capital intensity. However, the authors note that if the underlying reason for lack of returns is insufficient demand, governmental venture capital is unlikely to succeed more than IVC. They also find that public funding might improve the chances for an exit if channeled to startups that are lacking late round private investments. Bianchini and Croce (2022) find a country's commitment to environmental goals to be the main driving force behind clean tech investments made by GVCs. Furthermore, GVC funds emerge as an alternative incentive mechanism: in the event of underdeveloped direct government incentives the importance of GVC investments grows, indicating a substitution effect. Further, Bianchini and Croce (2022) point out that GVCs target later-stage rounds compared to institutional venture capital, indicating that GVCs support more mature companies as they navigate the 'valley of death', while also seeking broader strategic benefits, rather than solely focusing on financial returns like some IVCs. Guerini and Quas (2016) results show that GVC investment can increase high-tech entrepreneurial companies' chances of receiving PVC[2] at least threefold. The authors argue that these results suggest that GVC financing has a certification effect, where GVC can certify the potential of a startup to PVC investors and increase the startup's access to capital. Pantea and Tkacik (2024) review 34 studies on venture capital for European high-tech start-ups and find GVC to have lower but positive effects than IVC, and that GVC can supplement venture capital from private sources. As argued by Cumming (2007), it is hard to design an effective GVC program. van den Heuvel and Popp (2022) find positive evidence on public sector investments mobilizing VC investments in the context of clean energy. However, the authors also note that public investment does not improve the success rate of studied firms. Therefore, authors argue for the use of public demand-side policies instead. Bürer and Wüstenhagen (2009) study governmental energy policies for climate change, asking European and and North American fund managers to rate different policy options in terms of stimulating their investment interest. Results indicate that GVC funds received the lowest scores among several intervention options, reflecting skepticism among investors regarding governmental investing capabilities. This skepticism is captured in the sentiment that 'the government should not choose winners'.

[2]The authors define PVC as venture capital from private sources, such as independent VC, corporate VC and bank affiliated VC.

2.2.2 Debt

Corporate debt offers a way for climate tech startups to access larger pools of capital without diluting ownership. A McKinsey Quarterly article by Birshan et al. (2024) discusses challenges behind financing capital-intensive sustainable businesses. The article states that corporate debt can start from Series A and it is usually accessed through syndicated loans that include both commercial and public lenders, with the latter entering the investment earlier to mobilize private capital. Further, the authors note that in addition to banks, debt financiers can include non-bank entities, such as growth-lending agencies, alternative asset managers and direct-lender specialists. Pratty (2024c) discusses the role of debt in scaling climate tech, arguing that the second large wave of climate tech investments will be built on debt, with the role of debt financing becoming increasingly significant. This argument is supported by empirical data, as the author notes that in the first quarter of 2024, European climate tech companies raised three times more debt than equity financing, representing 93 percent of the total debt raised in the European tech ecosystem.

Lechtenfeld et al. (2023) point out that among one assessment within Tech for Net Zero alliance[3], more than half of the informants reported of investments that were either delayed or failed due to limited access to debt. Demirel and Parris (2015) results imply heterogeneity among the climate innovation financiers, suggesting that commercial banks avoid SME financing. Existing research suggests that when sustainable innovations reach the the commercialization phase, private equity, mezzanine and bank financing is often unavailable due to a lack of collateral or high risk of ventures (Polzin et al., 2016; Ughetto, 2008, 2010). Report written by ICF (2016) discovers the financing structures of sustainable energy technology FOAKs through interviews with different types banks. Interviews show that debt financing is rare because lenders are risk-averse, avoiding projects that do not have a proven ability to repay the financing. The authors suggest that one reason for this is the banks' increasing regulatory and capital adequacy requirements. Similar findings are presented more recently by Khatcherian (2022), who suggests that only mainstream, commercially proven projects – those following FOAK and possibly several subsequent projects – are likely to secure financing from more traditional lenders, such as commercial banks.

Interest rates on debt agreements are tied to current rates, with an additional percentage added depending on how well the asset linked to the debt – such as a FOAK plant or equipment inside it – is understood (Pratty, 2024c). Lechtenfeld et al. (2023) argue that as large share of climate tech startups operate in emerging sectors, they may often lack banks' creditworthiness criteria or are offered too high interest rates. However, the authors also note that while the

[3]Tech for Net Zero alliance is a collaborative initiative that brings together different stakeholders to accelerate the transition to a net-zero carbon economy. It was founded in 2021 as a joint initiative by the German Energy Agency, Breakthrough Energy and 1.5° Ventures. For more information, see https://techfornetzero.org/en/.

market risks for emerging climate technologies may be high, the machinery and the production methods of the products may be standard (Lechtenfeld et al., 2023). This is not entirely applicable to first-of-a-kind plants which involve a degree of technological novelty in their processes. Some FOAK plants, however, may use more standard equipment, resulting in higher collateral values (Enduring Planet, 2024), which may facilitate senior debt.

Cowling and Liu (2023) study clean tech innovators' access to debt in the context of high-tech small and medium enterprises, arguing that there are three main reasons behind why these companies face disadvantages in the credit markets. First, they face higher idiosyncratic risks due to uncertainty in innovation, higher transaction costs for external financing, and a lack of scale economies, leading to negatively skewed investment returns. Second, there is greater degree of information asymmetry; the novelty and lack of proven history make it hard for lenders to assess project quality before investment, resulting in higher risk premia. After investment, this asymmetry makes it difficult for lenders to monitor entrepreneurs, leading them to require physical assets as collateral, which high-tech SMEs often lack. Lastly, the founders are often scientists, lacking sufficient managerial skills. This can make these firms appeal only to a limited number of specialized investors, such as VCs.

Guarantees: Climate tech startups can reduce capital costs through credit guarantees, export credit guarantees or government guarantees (Birshan et al., 2024). Lechtenfeld et al. (2023) recommend use of a credit guarantees for FOAK projects that are able to sign offtake agreements, demonstrate technological readiness and illustrate sufficient forecasted cashflow. OECD (2022) find public guarantees to positively impact the availability of credit. However, Hargadon and Kenny (2012), who studied the DOE loan guarantee program during the Obama Administration, find that large loan guarantees might not produce the desired effects and that other government policies, such as grants, can yield better results. Polzin et al. (2019) find that guarantees have been proven to reduce risks especially in the context of novel technologies. The authors also point out that some of the negative evidence on guarantees might be explained by excessively funding low quality projects, leading to decreased investor sentiments.

Public lending: Public financial institutions can offer mechanisms that reduce risk and facilitate investment in climate technologies (Dafermos et al., 2020; Mertens & Thiemann, 2018, 2023). Both national and multilateral development banks seek to crowd in private financial actors by both de-risking investments and removing obstacles that are preventing certain actors from investing (Mertens & Thiemann, 2018). Public lenders play a pivotal role in both broader climate financing and the FOAK financing ecosystem. For example, European Investment Bank announced its goal in becoming European Union's 'climate bank' in 2019 (Mertens & Thiemann, 2023), and it is involved in the Breakthrough Energy Catalyst partnership, where private investment is blended with public funding and then channeled to demonstration and large FOAK projects (Breakthrough Energy, 2024b).

Mertens and Thiemann (2023) argue that public institutions have two important tasks in climate funding: reorienting finance towards climate goals and blended finance. Adopting a more climate friendly investment strategy involves divestments from carbon-intensive sectors, and a more systemic integration of climate issues into the lending processes. The authors note that this 'portfolio greening' is applicable to private lenders as well, but carries more weight if executed by reputable public institutions. The authors argue that this is because of three reasons: public institutions' role as benchmarking institutions or anchor investors, public institutions' stronger commitment to the environmental norms and public institutions' ability to provide long-term capital that suits the needs of climate transition. According to Mertens and Thiemann (2023), public financial institutions have also also implemented blended finance in the context of climate transition. Originating from the development finance context, blended finance is based on idea that public funds alone are insufficient to tackle climate change. This requires the mobilization of private capital through different mechanisms, such as risk-sharing arrangements. Blended finance is discussed further in Section 2.4.

Private credit: Alternative investment strategies, such as direct commercial and industrial lending by non-bank financial intermediaries has grown in the past decade, benefiting from long period of low interest rates (Chernenko et al., 2022). These private credit/debt investments have a debt-like nature and they are provided by various non-bank entities to fund private businesses (Cai & Haque, 2024). Private credit can provide a suitable form of long-term finance to firms that are seen too risky for banks and too small for public markets (Muminović, 2024), for example to climate transition financing through several structured investment opportunities (McDuffy et al., 2024). World's largest asset manager, BlackRock, launched a private debt fund that focuses on climate change mitigation in 2023 (Marsh, 2023).

2.2.3 Grants

Grants are often used to fund the proof-of-concept work in the beginning stages of a venture, reducing investor uncertainty about the new technology. Effects of governments directly subsidizing startup financing varies (Dalla Fontana & Nanda, 2023). Some authors argue that industrial grants have largest positive impacts for small businesses and startups (Criscuolo et al., 2019; Pless, 2022). According to Mukherjee et al. (2024), grants can de-risk early-stage projects and bridge the gap between innovative concepts and commercial viability. Cecere et al. (2020) point out that climate technologies need some form of direct public support in the transition phase where these technologies lack competitiveness and the effectiveness of other public policies is uncertain. Olmos et al. (2012) argue that grant efficiency can depend on existing funding gaps, technology's capacity to compete for public funds, associated technology risk and the type capital provider. Furthermore, the authors point out that grants for pilot projects are most costly form of intervention and should therefore be reserved for climate-positive projects that would not otherwise proceed or in cases where alternative funding mechanisms prove ineffective. Howell (2015) studies R&D grants in the context of energy startups. The author finds that early-stage public grants double the likelihood of subsequent VC financing, aid patenting efforts and increase the likelihood of becoming a successful business through attaining revenue. Islam et al. (2018) show similar results with a sample of US-based clean energy startups: the authors find that grant funding increases a likelihood of subsequent VC financing by 12%. Furthermore, the authors point out that the effect of grant receipt is observed only within six months, suggesting that startups rapidly use grants to strengthen their ties with VCs. Polzin et al. (2016) argue that public innovation intermediaries can accelerate the commercialization of climate technologies through both direct and indirect finance mobilization, and it is important to remember the case-specificity in financial mechanisms to achieve seamless transition within the innovation cycle. This can involve combining grants with private financing instruments when seen appropriate. Similarly, Olmos et al. (2012) find that funding schemes designs should consider both technological and market characteristics. Polzin et al. (2015) find that grants are beneficial during the research and commercialization phases but become less effective in the later stages of the venture. In terms of risk, Polzin et al. (2019) find no direct effect on renewable energy investment risk from the use of grants. Uyarra et al. (2016) study UK's institutional, governance and policy mixes for low carbon innovation. The authors find lacking consistency within the innovation policy, leading to uncertainty and potential impeding of private sector investment.

Table 3: Summary of selected publications on financing climate technologies

Capital source	**Selected publications**
All capital sources	(Carpenter & Petersen, 2002; Cecere et al., 2020; Demirel & Danisman, 2019; Demirel & Parris, 2015; Masini & Menichetti, 2013; Mazzucato & Semieniuk, 2018; Migendt, 2017a; Mukherjee et al., 2024; Olmos et al., 2012; Owen et al., 2018, 2020; Polzin et al., 2016; Polzin, 2017; Polzin et al., 2015, 2019; Uyarra et al., 2016; X. Wang et al., 2013)
All venture capital	(Pantea & Tkacik, 2024)
Independent venture capital	(Bocken, 2015; Bürer & Wüstenhagen, 2009; Criscuolo & Menon, 2015; Cumming et al., 2016; Dalla Fontana & Nanda, 2023; Gaddy et al., 2017; Halila & Rundquist, 2011; Knuth, 2018; Lerner & Nanda, 2020; Marcus et al., 2013; Migendt et al., 2017; Mrkajic et al., 2019; Nanda, 2020; Nanda & Ghosh, 2014; Nanda et al., 2015; Petkova et al., 2014; van den Heuvel & Popp, 2023; van den Heuvel & Popp, 2022)
Corporate venture capital	(Bansal & Roth, 2000; Hegeman & Sørheim, 2021; Hockerts & Wüstenhagen, 2010; Letout & Georgakaki, 2024; Wunder & Maula, 2024)
Governmental venture capital	(Harrer & Owen, 2022; Owen, 2023)
Debt	(Cowling & Liu, 2023; Leonard, 2014; Mertens & Thiemann, 2023)
Grants	(Howell, 2015; Islam et al., 2018)

2.3 FOAK financing challenges

This section explores the challenges associated with FOAK financing. These include return profile of climate hardware, combination of technology risk and capital intensity as well as other FOAK-specific risks, development time of climate infrastructure, lack of standardization and systemic innovation related to FOAK projects.

Climate hardware investments present several challenges for capital providers compared to other industries, such as information technology. These challenges include higher capital expenditure, higher level of risk, lower probability in scaling up and successful exit (Cumming et al., 2016; Nanda & Ghosh, 2014).

Lechtenfeld et al. (2023) discuss challenges behind financing capital-intensive climate tech facilities. The authors point out large upfront investments, extended path to profitability and vulnerability to shifts in market conditions and political environment. Furthermore, the authors highlight that climate tech startups cannot access all corporate finance options due to their high-risk nature. In terms of debt financing, many climate tech startups face 'innovation curse', where high risk aversion of banks prevents them from providing debt financing for innovative climate startups. Finally, the authors highlight that limited access to debt is further compounded by limited collateral and historical track as well as imbalance between the available short-term debt and long-term investment needs.

2.3.1 Return profile

Dalla Fontana and Nanda (2023) argue that climate hardware has often a lower potential for generating returns compared to software-based ventures (e.g., climate software) due to the scalability and asset-light nature of information technology. The authors highlight that the characteristics of software-based ventures improve the associated profitability and deliver higher cash flows to investors per unit of revenue, creating opportunities for outsized returns. Moreover, Gaddy et al. (2017) study A-round clean tech investments from 2006-2011 and find that investments in climate software generated returns for early-stage VC investors, while investments in climate hardware had a higher likelihood for failure, yielding lower returns.

Khatcherian (2022) argues that the risk, size, and return profile of climate infrastructure does not align with the characteristics of either venture capital or traditional project finance. Author highlights that project financiers focus on larger long-term projects with a smaller risk-return ratio. VC investors, in turn, focus on smaller short-term projects with higher risk-return ratios. Therefore, the investor focus areas do not align with FOAK plant investments, causing a mismatch between investor preferences and project characteristics.

van den Heuvel and Popp (2023) argue that many deep tech startups are typically selling their products to large incumbents with substantial market power and low willingness to adopt new technologies, resulting in lower profit margins. This makes them less attractive to prospective investors, especially VCs. Finally, the authors also highlight that customers can also be competitors, which makes the startups' value capture efforts even harder.

Green premia

Many FOAK projects' financial projections depend on green premia, which refers to the price difference between a lower-cost non-decarbonized product and a higher-cost decarbonized alternative. The decarbonized product can be similar to current alternatives, except for its net carbon emissions. As a result, the equity story may depend on the expectation of a green premium to drive higher returns. However, future demand is never guaranteed, increasing uncertainty of the financial models. In addition, FOAKs utilize novel climate technologies that often lack proven commercial models, further compounding uncertainty.

To examine the concept of green premia, we can consider the case of the Swedish startup Renewcell, which developed a patented process for textile production from textile waste. The company opened its FOAK plant in 2022, yet filed for bankruptcy only two years later (Renewcell, 2022, 2024). Tricia Carey, former Chief Commercial Officer of Renewcell, was interviewed about the reasons behind the bankruptcy in March 2024. In the interview, Carey highlights weak demand, partly caused by higher price point of the company's product, Circulose:

> *There was this whole hype that happened [with Renewcell], and it was very exciting to be a part of that. [...] And then it was sort of, okay, they want it, but not as much as they said they wanted it. [...] The markets have been talking about price and [saying], 'Oh, well, the price of Circulose is too high.' Is the price of generic fibers just too low right now? So the comparisons are not even fair. How do you compare a brand new material to a fiber that's been around for 100 years, and it's 5.6 million ton market? You can't, it's not an apples-to-apples comparison. (Deppen, 2024)*

Schabus et al. (2024) argue that some climate hardware solutions operate in commodity markets that are either enabled or heavily influenced by regulation. The authors note that these markets are typically highly price-sensitive, allowing limited opportunities for differentiation. Therefore, the added costs of sustainability – green premia – can make it difficult for companies developing first-of-a-kind assets to compete if they cannot offer a competitive price.

Nanda (2020) highlights that in the context novel technologies within underdeveloped markets, the risk that there will be a lack of market demand – contributing to low returns – can be substantial for VC investors. Agreeing with points raised by van den Heuvel and Popp (2023), Nanda (2020) raises concerns on the negative effect of large incumbents as customers. Further, Nanda and Ghosh (2014) emphasize the government's role in ensuring that decarbonized products achieve price parity with non-decarbonized alternatives.

Governmental actions can include initiatives such as carbon tax of conventional technologies, buying clean energy at a premium and subsidies through direct grants or tax-breaks. The authors note that regardless of the chosen policy, the profitability of a startup's product largely depends on whether it benefits from subsidies or credits, existing carbon taxes or, if the government acts as a customer, the price at which it agrees to buy the product.

Schabus et al. (2024) argue that while climate tech startups aim to lower costs to compete with non-green alternatives, they do not need to achieve price parity right away. The authors note that especially hard-to-abate sectors may not be able to reduce their emissions fast enough to keep up with increasing demand for green products. In the short term, this leads to certain customer segments being willing to pay higher prices for greener solutions.

Köveker et al. (2023) examine 24 studies on consumers' willingness to pay green premia. Most of the existing papers find a positive green willingness to pay, however, estimates vary. Most products are associated with a high green willingness to pay, while some have an intermediate to low green willingness to pay. The authors also note that there exists a consumer segment that is unwilling to pay any green premia. Further, the authors highlight the heterogeneity in green willingness to pay especially within renewable energy.

Exits

Schabus et al. (2024) study climate hardware exits and find that exits for clean tech startups have been challenging: during the first clean tech wave, startups struggled to find buyers, and even recent hardware IPOs have had lower market capitalizations compared to software IPOs. Moreover, the authors note that many corporations avoid acquiring high-risk ventures, especially hardware-related ones. Climate hardware exits have been limited, with most common exit form being smaller acquisitions with most common acquirors operating in the energy sector. Leveraging data from Net Zero Insights, the authors find that 69% of exits happened via acquisitions, with only 14% of climate hardware companies being acquired by financial investors.

According to Letout and Georgakaki (2024), number of exit opportunities for EU-based clean energy startups remain limited. Between 2015-2022, EU-based companies accounted for 6% of the global amount of acquisitions (US 62%; China 6%) and for 9% of the global amount of capital raised via IPOs (China 80%; US 10%). Furthermore, Gaddy et al. (2017) argue that early-stage clean energy investments underperformed between 2006-2011 compared to investments in other sectors. The authors highlight that clean tech companies had a lower likelihood in reaching a successful exit. Moreover, in the event of a successful clean tech investment, the associated return was lower compared to other sectors when measured by cash-on-cash multiples and IRR, regardless of higher risk levels.

2.3.2 Technology risk and capital intensity

Access to capital can drive innovation success (Halila & Rundquist, 2011). Bosio et al. (2024) find that limited access to external financing is one of the main difficulties of early-stage climate tech ventures. When looking at later-stage VC, climate tech has larger ticket sizes than other high-growth, high-tech sectors, such as quantum computing (Birshan et al., 2024). Hardware climate assets often require more capital than a startup's balance sheet can support, making it hard to raise funds. Furthermore, investors face difficulties in allocating required capital amounts entirely on an equity base, due to comparably low company valuations (Lechtenfeld et al., 2023). As a result, many large-scale climate investments face a scarce availability of funding while establishing commercial viability. This phenomenon has been characterized as the 'missing middle' or the 'valley of death' of funding capital extensive business ventures, such as climate and deep tech startups (Arora et al., 2024; Mittelmeijer et al., 2024), illustrated in Figure 5. At this stage, companies face challenges in securing the capital needed for commercial scale demonstration (Hudson & Khazragui, 2013).

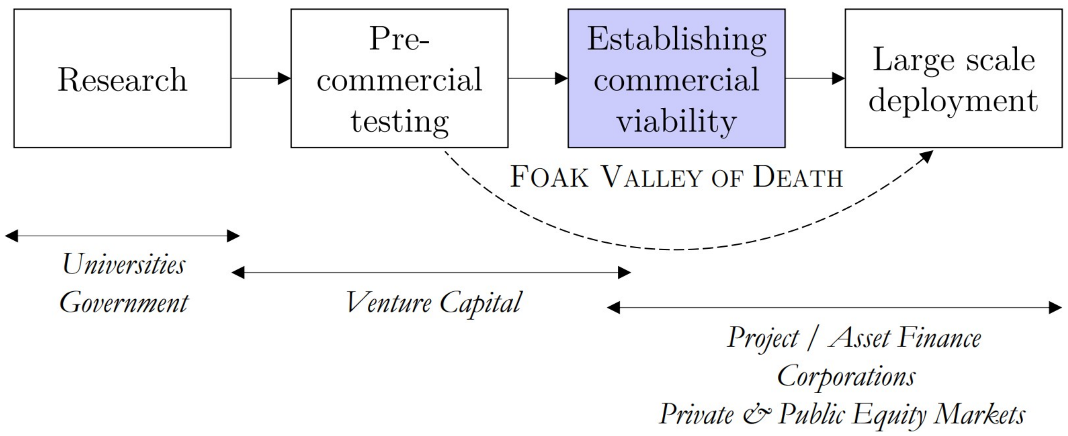


Figure 5: Valley of death in fundraising. Modified from Nanda and Ghosh (2014)

The Finnish Climate Fund (2024) highlights two distinct challenges in FOAK financing: the capital need is much higher than in earlier phases and FOAK investments are intermediaries in terms of private financing. Latter is particularly true for three reasons. First, FOAK projects still contain technology risk, so they do not fit the business model of more risk-averse financiers, such as infrastructure investors. Second, the capital need for the FOAK project is both too large and the repayment periods are too long for early-stage VC funds. Third, and in the context of Finland, the projects are often too small for large late-stage international VC funds, whose investments are generally challenging to attract to Finland.

Nanda and Ghosh (2014) discuss venture capital in the context of clean energy sector. The authors highlight that since startups lack sufficient internal funds and are considered too high-risk for project or debt financing, venture capital becomes the primary mechanism for their commercialization. However, from the investor's perspective, financing demonstration and first commercial plants present a significant challenge, as these investment costs for these projects can range from tens of millions euros to single billions of euros, which are often too large for traditional venture capital but still too risky for both infrastructure and or PE funds. Moreover, Nanda and Ghosh (2014) argue that inability to close the funding gap can lead to venture capital drying even in the pre-commercial stage.

Previous literature suggests that often times private investors' prefer asset-light industries over asset-heavy industries (Libert et al., 2016) and that traditional private lenders often avoid financing technologies that lack previous larger-scale demonstration (Frank et al., 1996). Differences in access to capital are seen both when comparing non-climate startups with climate startups, as well as between different types of climate startups. Some research suggests that access to capital is harder for companies that are developing green innovations, compared to companies in other sectors (Halila & Rundquist, 2011). Several authors have pointed out that climate software startups have better access to early-stage capital than climate hardware startups (Bumpus & Comello, 2017; O'Reilly, 2023). However, some authors find no definitive proof on financial constraints, such capital intensity, causing VC investors to miss out on profits within clean energy (van den Heuvel & Popp, 2023).

In their 2014 Harvard Business School technical note, Nanda and Ghosh (2014) present a risk-capital intensity matrix in the context of commercialization of clean energy technologies, illustrated in Figure 6. They argue that technologies situated in the left-hand quadrants of the matrix – where technology risk is high – are often too risky to attract debt financing. Over the past decade, debt financing for infrastructure projects like wind power has matured and become commercially viable (Kanoff et al., 2023a). This development is due to advancements in technology, economies of scale, and policy support. As a result, even commercial banks have increasingly participated in these projects (Danske Bank, 2023).

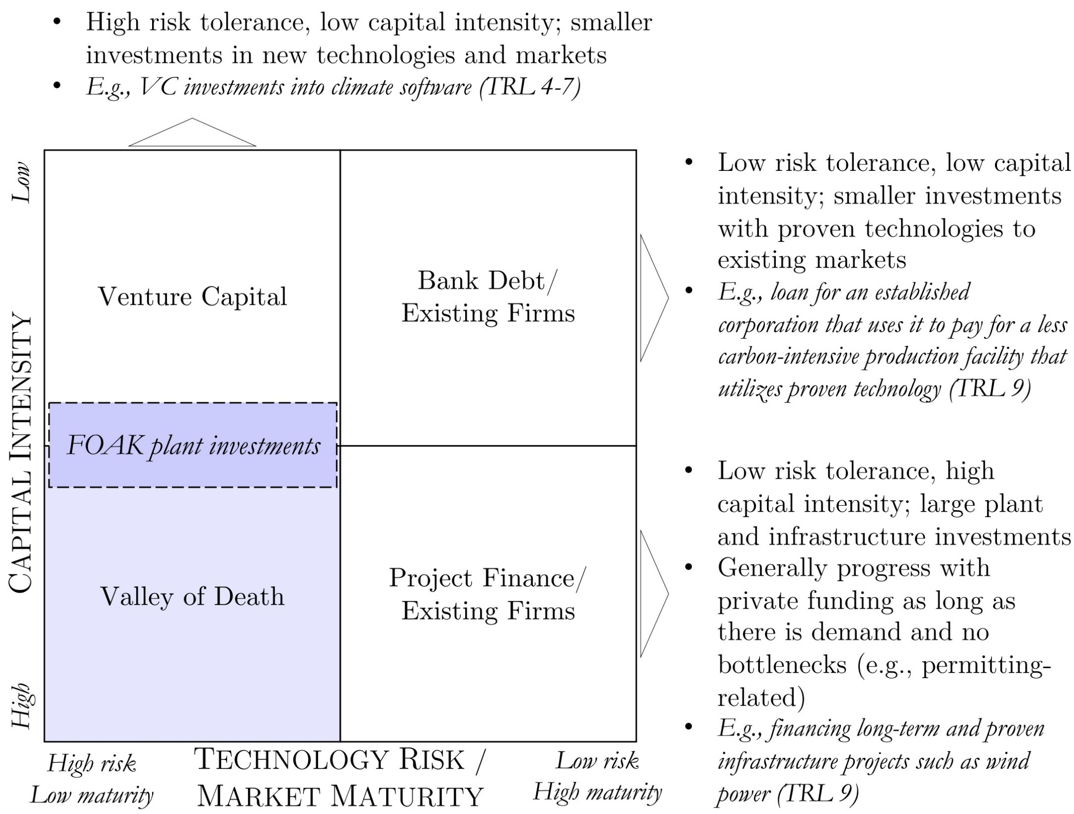


Figure 6: Risk-capital intensity matrix for commercialization of capex intensive technologies. Modified from Nanda and Ghosh (2014) and The Finnish Climate Fund (2024)

The position of the dashed box relative to the axes in Figure 6 demonstrates how FOAK plant investments are intermediaries between different investor types (Nanda & Ghosh, 2014; The Finnish Climate Fund, 2024). When examining the dashed box's relationship to the y-axis, it should be noted that these investments do not typically represent the largest capital needs within the 'valley of death'. Larger projects, such as billion-euro plant investments (e.g., green steel producer Stegra) demonstrate significantly higher capital requirements due to market characteristics of the steel industry (The Finnish Climate Fund, 2024). Stegra can be considered a FOAK project (Nikkilä, 2024) due to the novelty of the demonstrated process. However, its capital requirements are substantially higher compared to other FOAK projects that are explored within the scope of this thesis.

Recent empirical findings show that the 'valley of death' remains a problem within climate tech. According to a report made by Finnish Industry Investment (2024), software-based climate tech ventures raise funds more faster in the first funding round than capital intensive climate hardware ventures, who are lagging behind. Moreover, the study points out that the widest funding gap exists at the later stages of the funding, where the industrialization takes place. Authors also point out to the lack of Nordic dry powder to fund the growth of clean tech companies. The report presents three potential ways to bridge the funding gap: establishing more climate tech-specific late-stage funds, increasing the amount of international investments as well as promotion of a larger involvement from current generalist funds.

O'Sullivan and Raghavan (2023) also find capital imbalances in a global scale. The authors argue that current financing structures have two main problems: one related to capital distribution and the other related to ticket sizes. First, the market is saturated with capital aimed at either early-stage high-risk ventures or late-stage de-risked investments, creating a gap in growth equity financing that bridges the two stages. Furthermore, the authors find that most of the available EU and US growth-focused capital is held in large funds, which offer too large ticket sizes. This mismatch limits startups' access to appropriately sized financing.

Dalla Fontana and Nanda (2023) highlight that one issue with capital intensive startups that are developing novel climate technologies is that venture capitalists have a high sensitivity related to how much capital is needed to reach early milestones in order to reduce the associated risks. The authors explain this through skewed nature of risk and return in VC, which leads them to invest in stages (experiments) that generate information about whether a given startup will fail or win. This leads to venture capitalists preferring asset-light software startups, as these startups allow fast experimentation. This, in turn, makes the investors' real option to stay or leave in the next round more valuable, increasing likelihood to future success. Further, Nanda (2020) argues that since startups' ability to produce at a certain price is tied to demand, technology and market risk can often be dependent on each other. The author highlights that often the capital needs of the commercialization process might be too large from the venture capitalist's point of view, as the de-risking process might involve building hardware – such as a FOAK plant – before truly understanding the associated disruption potential.

2.3.3 FOAK-specific risks

FOAK projects encounter various risks which go beyond just technology risks. These include uncertainties related to new business models, engineering, development and market readiness (Donnelly, 2023). For example, being a first mover means there is a chance the technology may not deliver the expected output, affecting financial projections. Another challenge may arise from underdeveloped markets, as investors may question a product's projected success relative to both non-decarbonized and decarbonized alternatives in the sector. Moreover, as mentioned in the previous section, predicting unit costs for novel technologies can be difficult – regardless if the technology has been proven in a laboratory scale before moving on to commercial scale.

Technology risks are often discussed in the context of clean technologies (Nanda & Ghosh, 2014), arising from the novelty of the technologies. The transition from pilot/laboratory scale to industrial scale involves significant technological risks (ICF, 2016). Despite thorough preparation, certain issues can only be addressed through practical implementation of a larger scale projects. Moreover, Khatcherian (2022) highlights that FOAK projects become commercially proven only through several implementations and continuous operation.

Nanda (2020) argues that in the context of 'tough tech' innovation, the venture's ability to de-risk depends on two important drivers: technology and market risk. Furthermore, the author argues that since startups' ability to produce at a certain price is tied to demand, technology and market risk can often be dependent on each other. The author further emphasizes that market risk is particularly high in sectors with heavy regulation or significant government involvement. Moreover, governmental intervention can play a critical role in de-risking ventures. The author points out historical examples where startups successfully achieved commercialization through combination of VC and governmental support.

FOAK projects are influenced by the political environment in which they operate, exposing them to political risks. For example, Polzin (2017) find that since many low-carbon technologies' applications may rely on a supportive political climate, risks related to policies can form major obstacles for potential investment. Furthermore, van den Heuvel and Popp (2023) link some of the challenges behind the first wave of clean tech to a US Senate election in 2010, where the unexpected victory of Republicans led to the failure of a comprehensive climate bill. The authors point out that this political change caused many VCs to lose interest in clean energy startups. More recently, Rotman (2023) highlights how changing political dynamics could disrupt – again – the current wave of climate tech investments.

According to Mazzucato and Semieniuk (2018), most renewable energy investors tend to focus on one or two high-risk technologies rather than diversifying across multiple high-risk options. This selective approach means that investors 'push' development in certain directions. The authors point out that public banks are an exception, as they invest more broadly across various high-risk projects. Furthermore, Masini and Menichetti (2013) find that renewable energy investors are highly influenced by factors such as application's technical feasibility, proven performance and existing institutional pressure. The authors suggest strengthening these aspects through public and private R&D programs, promotion of demonstration projects and information sharing.

2.3.4 Development time

As discussed in Section 2.3.2, climate hardware often requires substantial investment in physical assets, slowing the commercialization journey. This is especially true for climate tech startups whose business models require building capital intensive factories to manufacture their products. According to a report made by ICF (2016), various project-related and external factors explain financier attitudes towards strategic energy technology FOAK financing. One project-related challenge is the long time-to-market of these innovations. The report concludes that the time required to plan, permit and deploy a FOAK project frequently exceed the financing horizons of many financiers.

Capital providers' sensitivity to development time varies. Dalla Fontana and Nanda (2023) highlight that venture capitalists, in particular, are impatient in reaching initial de-risking milestones. The authors note that although VCs can extend the life of a fund for a few extra years, the fixed timeline of around 10 years often becomes a major constraint in science-based deep tech innovations. Finally, the authors emphasize that this is a specific issue for startups that build factories to produce their products.

Khatcherian (2022) discusses reasons behind lengthy timelines to widespread adoption of capital-intensive climate infrastructure. Challenges include the need to demonstrate technological reliability, establish customer adoption and prove scalability in production. Additionally, the author highlights that the readiness of adjacencies, such as supporting infrastructure, is often required alongside overcoming extended project development timelines and high costs. Bottlenecks related to regulation, dependencies and the necessity for achieving economies of scale and technological novelty further compound the issue.

2.3.5 Lack of standardization

Climate-related FOAKs face lower standardization compared to more mature technologies due to their innovative nature and the lack of established industry norms. First-of-a-kind assets often lack proven market or technical track record. For example, a FOAK plant might use well-known machinery, but the specific combination and scale of these components in the context of the FOAK project has never been tested before.

Lack of standardization makes it harder for capital providers to determine the suitable risk adjusted returns which is a prerequisite for investing, leading to greater information asymmetries. Asymmetries already exist within clean technologies: for example, Cowling and Liu (2023) find that novelty and lack of verified experience of clean tech innovations cause information asymmetries, resulting in higher risk premia for the lenders. Moreover, Khatcherian (2022) argues that FOAK projects specifically lack standards and process certification. This may lead to even greater information asymmetries, as non-specialized financiers struggle to sufficiently assess the quality of a project that is deployed for the first time.

Lack of standardization raises another concern related to regulation. According to technology neutrality, particular technologies should not be favored, leaving technological choices to the markets (Djakonoff et al., 2024). Djakonoff et al. (2024) find that technological neutrality is likely to preserve market diversity. The authors highlight three factors for maximizing public good in the context of green transition: case-specificity, inter-sectoral co-operation and related long-term leadership. Further, Polzin et al. (2019) point out to trade-offs between technology specificity and neutrality in the context of renewable energy. For example, technology specificity offers favorable conditions to less mature technologies and technology neutrality favors most cost-efficient technology.

Technology neutrality may fail to provide the targeted support or incentives necessary for emerging technologies to overcome the challenges of early-stage development (Carpén, 2023; Djakonoff et al., 2024). In some cases, regulation can unintentionally hinder innovation when regulatory bodies fail to establish clear frameworks for emerging technologies. This regulatory gap can make FOAK startups in less-mature industries less attractive to investors compared to technologies already operating under established regulations, defeating the purpose of technology neutrality by prioritizing existing technologies over innovative ones. According to report made by International Energy Agency (2024), regulatory uncertainties were among one of the most common barriers for hydrogen project developers. The report points out that there are currently no clear and stable regulatory frameworks, leading to some companies pausing or postponing projects.

Carpén (2023) studies technological neutrality in the context of innovation policy design in Finland. Interviews with two Finnish climate technology startups reveal that while the other startup has avoided the regulatory burdens of hydrogen technologies due to being regulated by the main product's industry, the other startup has faced challenges with the availability of public financial instruments due to not fitting into the industry boundaries of support programs. The study reveals that government policies can include situations where technology providers are treated unequally. For example, application-specific standards can treat the same technology user groups differently based on the application area.

2.3.6 Systemic innovation

As presented by Chesbrough and Teece (1996), the term systemic innovation relates to innovation where the benefits of the innovation can only be fully realized when combined with related, complementary innovations. This implies that startups that rely on fundamentally systemic innovations can enhance the associated benefits through collaboration with external partners. Furthermore, Maula et al. (2006) find that innovations have a growing systemic nature, leading to greater reliance by companies on external partners.

First-of-a-kind projects often rely on systemic innovation. For example, climate-friendly FOAK plants may use green hydrogen as a key input in the production process in order to minimize the environmental impacts of the process. The companies can either produce the hydrogen themselves or buy it from external partners. As a result, startups are heavily affected by the development of the hydrogen ecosystem, as in the absence of external hydrogen producers, they need to produce the hydrogen by themselves (and invest in needed infrastructure, such as electrolysers). Hydrogen electrolysis requires a substantial amounts of electricity. Therefore, electricity might become a primary variable production cost. Purchasing hydrogen from external partners can have the potential to significantly reduce the electricity required for production, reducing operational costs. However, the current green hydrogen supplier ecosystem, both domestically and globally, is still immature. For instance, Finland currently lacks domestic green hydrogen suppliers. Some projects, such as P2X Solutions, are currently ramping up production (Paukku, 2024).

2.4 FOAK financing structures

The previous sections explored different FOAK capital sources and the challenges associated with FOAK financing. This section focuses on understanding how to effectively structure FOAK financing, building on earlier insights to combine different capital sources and address identified challenges.

2.4.1 FOAK capital stack

Green innovation businesses need several forms of financing as they grow (Owen et al., 2018) and large-scale patient capital for clean tech requires a combination different capital sources (Owen & Vedanthachari, 2023). There is a heterogeneity in the context of young firms' capital providers in general (Pahnke et al., 2015) as well as within separate investor groups such as CVCs (Wunder & Maula, 2024). Further, Section 2.3 highlighted why various capital providers may find financing FOAKs challenging. The findings highlight that combining different types of capital can provide the necessary resources to de-risk and scale FOAK climate projects.

The prevailing argument suggests that an optimal FOAK financing structure has a balanced combination of different types of capital, such as equity, debt, quasi-equity and non-dilutive grants (Khatcherian, 2022; OCED, 2024; Pratty, 2024b; Reem, 2023). Debt and grants offer advantages in terms of lower capital costs and reduced equity dilution (Rivera, 2024). Financing sources can be dependent on each other and commitment of one kind of financing can trigger the close of others (Climentum Capital, 2024). Given the dependency and involvement of various capital sources in FOAK projects, several fundraising streams must be coordinated and executed in parallel to ensure alignment of financing mechanisms and, ultimately, the overall success of the project. Illustrative FOAK financing structure is shown in Figure 7.

Discussion around financing emerging climate technologies has gained momentum, with a focus on the need for a diverse range of financiers (Nikkilä, 2024; Pratty, 2024a; Wharton et al., 2024). Some argue that optimal FOAK financing structure is composed of equal amounts of debt, grants and equity (Pratty, 2024a), while alternative models advocate for a 50% equity and 50% grant structure, with the possibility of incorporating up to 30% debt if offtake agreements are in place (Reem, 2023). Offtake is an agreement where one participant ('the Offtaker') buys all or some portion of the output of a given plant (Thomson Reuters, 2024), providing a guarantee of future revenue. Offtake agreements are frequently seen critical in securing the confidence of potential financiers (Pratty, 2024b; Reem, 2023). Large-scale offtake agreements can ensure high upfront investment repayment (Climate Brick, 2024), de-risking FOAK projects.

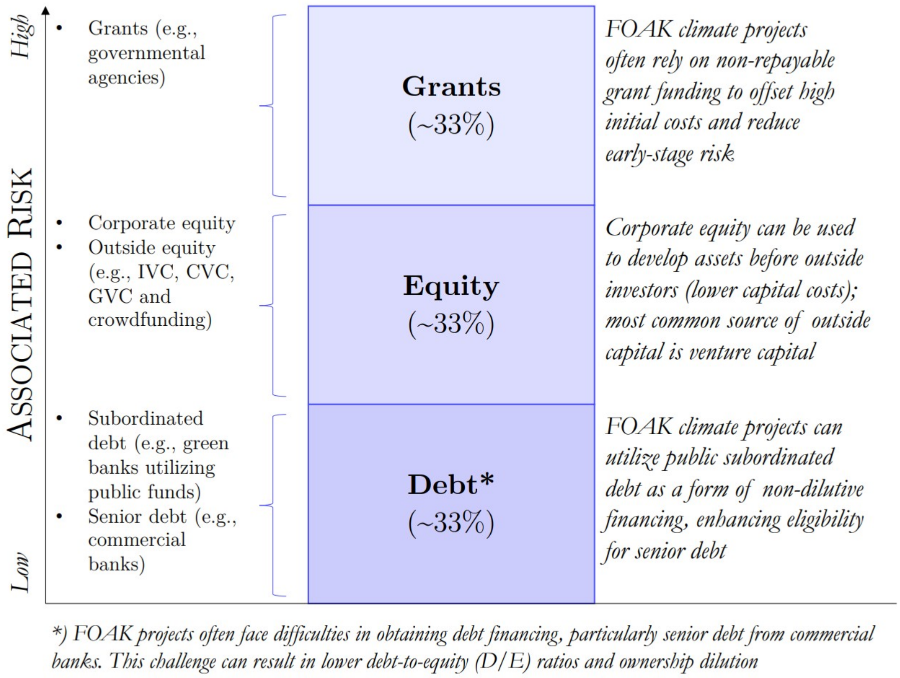


Figure 7: Illustrative financing structure

A recent report published by Finnish Industry Investment (2024) studies the Nordic clean tech market. According to the report, financing structures within industrial clean tech projects, including FOAKs, include various capital sources, such as equity, debt and grants. Some of the projects also employ project financing as a funding model. The authors note that high riskiness of the venture increases the share of equity. According to the report, hardware climate tech startups often first use internal equity funds to develop FOAKs before utilizing outside capital, as venture capital can be an expensive form of financing.

A recent report written by OCED (2024) studies eight companies with 21 demonstration and deployment projects, defined as FOAKs. The report finds that FOAK projects require flexible and diverse financing strategies, balancing initial reliance on corporate equity with opportunities for structured financial products to evolve the capital structure over time. Early demonstrations' risk profiles are rarely suited for project-level debt or equity, and corporate equity is the primary source of capital. Early deployment projects may be able to secure project-level debt, though with very strong protections for lenders and guarantors. Early demonstration projects with strong commercial propositions may get access to structured financial instruments. Companies utilized several products such as equipment finance, corporate revolving credit facilities as well as construction loans that were supported by insurance.

A less recent report written by ICF (2016) discovers financing structures of sustainable energy technology FOAKs. Results show that grants play an important role, varying between 10-30%, with some larger outliers. Equity varies between 10-30% in many projects, while debt varies from 10% to more than 70%. Debt raising is easiest for FOAK projects that are operating in the most mature sectors. Bond finance and internal company financing is scarce, being hardly mentioned by the informants.[4]

2.4.2 Blended finance

Blended finance refers to blending capital from public and private sources. Example of blended finance in the FOAK context is presented in Box 1. According to Mertens and Thiemann (2023), public institutions, such as government-owned banks, can offer mechanisms to de-risk and facilitate investment in climate technologies. The authors argue that public institutions can make investments based on the idea that certain investments may offer significant ecological benefits in the long-term, but may not appeal to profit-driven or risk-averse investors in the short-term. Therefore, they underwrite risk and debt, take on the role of cornerstone investors and absorb losses as co-financiers with the goal of mobilizing private capital.

OECD (2016) report discovers green investment banks' role in terms of crowding in private investment for climate-friendly infrastructure. Public institutions can make both equity and debt investments in projects/companies. Public financiers often avoid majority equity stakes to facilitate private capital. The authors highlight public institutions' role not only as capital providers, but as indirect risk mitigants for private investors. For example, equity investments are repaid only after debts are settled in cases of default or bankruptcy. This makes public equity investments reassuring for private lenders, as they have repayment priority and can expect public financiers to actively work toward recovering their equity, further de-risking the project.

According to OECD (2016), public institutions can provide loans to projects that would else fail to reach the construction phase. The authors point out that climate-positive climate infrastructure projects often require bank loans in addition to corporate and outside equity due to larger capital needs. Loans are the most common instrument of public green investment banks. The authors also highlight that public institutions can align loan repayment schedules to the project's revenue generation timeline or cost savings. This flexibility enhances the likelihood of repayment, improving the project's chances of financial success. Credit-enhancing mechanisms offered by public institutions can de-risk a project or investment that initially fails to meet the return expectations of private lenders, making it more viable for private sector participation. Next, some of the main credit-enhancing risk mitigants are discussed in further detail.

Loan loss reserve funds from public sources: OECD (2016) report highlights loan loss reserve funds as one credit-enhancing mechanism of public institutions. According to OECD (2016, p. 64), "loan loss reserves set aside capital to cover potential losses and help to reduce repayment risk." The authors further describe

[4] The majority of projects discussed in the interviews for this report had not yet finalized their financing contracts. As a result, the financing structures are indicative.

the loan loss reserve funds' mechanism: if a borrower (such as a FOAK developing climate technology startup) defaults, the lender is repaid using the reserve fund. The authors also highlight that public investors may offer a portion of loan loss coverage for lenders.

Guarantees from public sources: Guarantees can be a great credit enhancement tool and public credit guarantees can offer an efficient instrument to catalyze more private capital as they can make projects creditworthy or 'bankable' by providing a form of insurance to other capital providers against risk of default or non-payment (Lechtenfeld et al., 2023). Some authors have found evidence on guarantees being among the most fiscally efficient instruments in stimulating industrial activity (Bachas et al., 2021). Guarantees can also reduce capital costs (Lechtenfeld et al., 2023). According to Finland's state-owned export credit agency Finnvera (2024), its guarantee coverage is project specific, and it usually covers 50–80% of investment amount. For instance, the debt facility for a Swedish startup Renewcell's FOAK plant was backed by Finnvera for up to 85% (Nordea, 2021).

A/B loan structures from public sources: In A/B structures, public institutions provide direct loans and act as lender of record for loans that are funded by commercial banks, allowing commercial banks to benefit from the applicable privileges and immunities of the public institution (Clifford Chance, 2023). A/B structures can facilitate private financing by de-risking the commercial banks' participation (Clifford Chance, 2023). Nordic Investment Bank (2024) offers A/B loan structures where it is the lender of record, administering the loan. As stated by Nordic Investment Bank (2024), "NIB keeps the A loan for its own account while the B loan is funded by commercial banks pursuant to a 'Participation Agreement'. The borrower benefits from longer tenors and higher-value financing. NIB fully shares project risks with the participating banks which are able to share NIB's privileges as an international financial institution." According to Nordic Investment Bank (2024), A/B structures enhance the delivery of its mandate.

Subordinated debt from public sources: Public financiers can provide subordinated debt, such as junior loans, to finance climate technologies. According to Leonard (2014), subordinated debt operates on a premise where the public financier agrees to subordinate its tranche of debt below that of the other lenders. This allows private lenders to be given priority for repayment in the event of a failure of the project (i.e., default/bankruptcy). Subordinated debt is discussed further in the FOAK context in the next section.

Box 1: Blended finance in the FOAK context:
Breakthrough Energy Catalyst Partnership (EU)
Breakthrough Energy's Catalyst program combines private financing from Breakthrough Energy with public financing from the European Investment Bank and the European Commission to fund demonstration and large FOAK projects (Breakthrough Energy, 2024b). One of the program's investments is EUR 75m in financing towards energy storage solutions designed to support industrial decarbonization (Rondo Energy, 2024).

2.4.3 Mezzanine finance

Mezzanine finance combines features of both debt and equity financing, and it can especially suit the varying needs of investors in clean energy technology deals (Y. Wang, 2024). X. Wang et al. (2013) discuss ways to unlock commercial financing for clean energy, mentioning mezzanine financing as one form of suitable instrumentation. According to the authors, mezzanine finance comes in two major forms, subordinated loans and quasi-equity. These forms can be embedded in one financial instrument, as shown in an example of a subordinated debt instrument in the context of FOAKs presented in Box 3. Subordinated loan represents a loan that stands behind other investors in the event of liquidation or bankruptcy. Quasi-equity, in turn, represents convertible loans with patient and flexible payment terms. Example of a quasi-equity instrument in the FOAK context is presented in Box 2. The authors note that mezzanine finance represents a versatile form of debt financing that allows larger risk taking than traditional form of finance, and it is also one of the most versatile of public instruments. The authors also note that subordinated debt can be used to extend loan terms, enhancing cash flows and the overall viability of a project. The authors argue that a mezzanine loan can solve two distinct issues climate tech startups can face: debt and equity gap. These are discussed further below.

Debt finance gap: First, X. Wang et al. (2013) highlight startups' inability to secure senior debt from commercial banks due to high default risks. Banks can finance up to 80% of well-established and proven technologies, however, for novel projects – particularly FOAKs – financing levels are typically reduced to less than 50%, reflecting the uncertainty within untested technologies (Rivera, 2024). X. Wang et al. (2013) argue that subordinated debt can provide up to quarter of the investment cost of a given project. This in turn, reduces the amount of needed senior loan financing, improving the loan-to-value and debt service coverage ratios of senior lenders.

Equity finance gap: Secondly, X. Wang et al. (2013) argue that a convertible loan instrument can help bridge the equity finance gap that occurs when the investor's equity is inadequate in meeting the minimum equity requirement for loan eligibility or when a startup is unable to obtain financing from commercial banks. A convertible loan is a form of unsecured debt that does not require collateral. Instead, it allows lenders to convert their loan into equity ownership if the borrower defaults. By providing an alternative to traditional equity, a convertible loan enables the startup to secure financing without needing to meet equity requirements upfront. This arrangement helps close the equity gap by offering a potential ownership stake to the lender, making it easier for startups to access funds when they have limited equity or collateral.

Box 2: Quasi-equity in the FOAK context:
Elemental Impact (US)

Elemental Impact's D-SAFE instrument is designed to streamline development funding. According to Elemental Impact (2024), it has a dual functionality that includes both a redemption and a conversion clause. The former allows it to either operate like a loan and get paid back at the company's option and the latter allows it to convert to equity (i.e., traditional SAFE at the investor's option). Elemental Impact (2024) highlights that if the investment is successful, financier can convert the instrument into a loan to be paid off. Conversely, if the project fails, the financier can convert the investment into equity.

Box 3: Subordinated debt in the FOAK context:
The Finnish Climate Fund (FI)

The Finnish Climate Fund was a government-owned organization focused on financing industrial climate scale-ups, such as FOAKs. According to The Finnish Climate Fund (2022), one of the company's objectives was to catalyze private financing. The fund's main instrument was a capital loan (*fin: 'pääomalaina'*), form of mezzanine financing that allows the principal and interest to be subordinated to other creditors in the event of liquidation or bankruptcy (MiniLex, 2024). These loans do not generally increase equity, yet they can be be included in the equity calculation for solvency assessments (The Finnish Climate Fund, 2022). The Finnish Climate Fund (2022) highlights suitability of capital loans for startups for whom the subordinated nature can facilitate further financing, and for whom the return component – often based on conversion right – is a natural part of the overall cost of financing.

2.4.4 Asset-based finance

The capital intensity of FOAK projects presents certain advantages. Some FOAK projects can use their physical assets, such as equipment, as collateral to secure financing. As senior debt is often secured by company assets such as property or equipment, high collateral values can facilitate the participation of senior lenders in FOAK financing structures. The following paragraphs explore key considerations on asset-based finance in the context of FOAKs.

Maximizing collateral for downside risk protection: According to Enduring Planet (2024), collateral values of FOAK plants can depend on the sector and novelty of the application, as some FOAK projects might use relatively standard equipment, which can hold value even in the case of company's liquidation or bankruptcy. The authors give battery recycling as an example of an industry where the equipment can generally retain some value. However, other FOAK projects might utilize more modified equipment, which affects the ability for reselling. For example, the authors highlight that sustainable aviation fuel projects use custom-built reactors, which are typically difficult to resell in default scenarios.

Detailed valuation of the FOAK plant: Pratty (2024a) argues that in order to increase the investment readiness for senior lenders, FOAK developers should have a comprehensive understanding around the valuation of the project's components, as especially debt providers require a thorough understanding of the repayment capabilities in the case of liquidation or bankruptcy. The output of this valuation process is the secondary market value of critical assets, such as machinery or equipment of the specific FOAK plant.

Use of leasing/renting structures for distinct parts of FOAK plant: FOAK projects include different tangible project elements, such as the facility ('the walls of the building'), machinery and equipment. According to Climentum Capital (2024), these isolated elements can be financed using various mechanisms. For example, machines can be financed with either traditional debt or through the use of equipment financiers. The authors note that tangible assets can be eligible for traditional debt financing due to higher collateral values. On the other hand, OCED (2024) highlight that in the absence of FOAK bank financing, equipment financiers – who have a lien on physical equipment rather than the project's integrated assets or cash flows – can be used to finance the assets. Equipment financiers are not similarly exposed to the binary risk associated with the FOAK project's outcome as the other capital providers (OCED, 2024). Example of equipment finance in the FOAK context is presented in Box 4.

Attractive asset-backed structured investment opportunities arising from new regulation: Recently, some private financial institutions, such as Goldman Sachs (McDuffy et al., 2024), have highlighted the attractive risk/return opportunities within structured investment opportunities. These opportunities are arising from new climate regulation, such as the Inflation Reduction Act in the United States. For example, senior debt secured against tangible assets, such as equipment inside facility, can be repaid via cash from clean tech product sales and government receivables through 'direct pay' tax credits for businesses that manufacture and sell energy components (McDuffy et al., 2024).

Box 4: Equipment finance in the FOAK context:
Solugen (US) and Via Separations (US)

According to report made by OCED (2024), two companies that were in large-scale pilot and early demonstration phases funded up to one-third of upfront FOAK project costs through equipment leases. The report states that in mature infrastructure projects, large equipment suppliers can provide financing to large developers or EPC firms. However, these structures are often inaccessible to smaller developers. Solugen and Via Separations utilized a third-party equipment financier to structure a lease that combined eligible equipment from their projects' bill of materials into one financing package.

2.4.5 Project finance

Project finance refers to a funding model for large-scale, long-term, capital-intensive projects. As noted by Birshan et al. (2024) in a McKinsey Quarterly article, certain capital-intensive climate tech startups have adopted project financing, typically starting from Series B onwards. Report made by Finnish Industry Investment (2024) discusses the financing of industrial clean tech projects. Authors note that some clean tech projects may utilize use of special purpose vehicles ('SPVs'), where debt and equity are both legally and financially separated. Projects can also have several forms of financing, such as tax equity, construction debt and back leverage. The report further highlights use of 'non-recourse' -structures, where lenders and investors primarily bear the risks at the project level and are granted step-in rights to take over the project management in the case of a default. Example of project finance in the FOAK context is presented in Box 5.

Knuth (2018) discusses financialization in the context of clean energy transition. According to Knuth (2018), industrial renewable energy projects based in the US have since their inception relied upon project finance, where developers create a special purpose vehicles ('SPV'), legally separated entities. These entities' only purpose consists of building and/or operating a large project, such as a large industrial plant. The SPV – which typically hold the project's assets – takes on a high rate of debt from capital providers, which it pledges to repay through the revenue generated from the project. The author notes that the complexity of these deals make project financing an expensive form of capital, which is why it is usually used for more larger projects. Similarly, X. Wang et al. (2013) argue that offering limited-recourse financing for smaller projects may not be feasible because their size doesn't justify the complex processes required.

OCED (2024) report finds that for studied US early FOAK demonstrations, project-level financing is rare. The report also states that while vast share of the available resources for FOAK project developers aims to educate startups on the expectations of late-stage investors, the strategies are only readily accessible and/or cost effective for technologies that are already in late deployment – not novel FOAKs. These strategies can come in the form of project finance checklists, including long-term, credit-worthy offtake agreements with fixed price/volume, thorough engineering, procurement and construction (EPC) contracts and strict operational processes managed by a well-experienced project team. Project financing is already well-established in sectors like wind and solar energy (Birshan et al., 2024). According to Khatcherian (2022), project finance capital providers do not see the first implementation of a FOAK project as a prospective investment as they see it as a commercially unproven project, needing several iterations before prospective investment.

Box 5: Project finance in the FOAK context: Renewcell (SE)

Export and project financing enabled Renewcell to build their FOAK textile recycling plant. According Nordea (2021), the startup entered into a SEK 450m loan facility agreement with Nordea, Swedish Export Credit Corporation and Finnish export credit agency Finnvera. As stated by Nordea, both the parallel IPO and the guarantee from Finnvera was crucial for close of the debt financing. This case demonstrates a financing strategy where equipment suppliers are selected in a way that export credit agencies from other countries can collaborate in the guarantee of the loan, enabling the startup to secure the export deal.

2.4.6 Offtake agreements

Offtake agreement is an agreement where an one participant ('the Offtaker') buys all or some portion of the output of given plant, supporting the feasibility of the project (Thomson Reuters, 2024). This arrangement provides a guarantee of future revenue and is often an instrumental element in project financing structures. Large-scale offtake agreements can ensure high upfront investment repayment (Climate Brick, 2024), limiting the risks of FOAK projects. Furthermore, offtake agreements can help FOAK startups to reassure lenders to grant debt financing (Pratty, 2024b). Electricity sector, including solar and wind projects, have historically secured long-term offtake agreements and highly structured project finance (OCED, 2024). Many climate tech startups operate within underdeveloped markets, yet to reach similar maturity in terms of project financing (Birshan et al., 2024; OCED, 2024). Example of offtake agreements in the FOAK context is presented in Box 6.

OCED (2024) report on FOAK financing highlights that offtake agreements in FOAK projects depend greatly both on sector-tied demand and the novelty of technology. The authors find that in the case of strong demand for the FOAK product's environmental features, startups can secure long-term offtake agreements. Further, if the FOAK startup is unable to secure offtake agreements, it can used alternative strategies to de-risk revenues, such as generating a diverse cross-industry customer base and pursuing differentiation where feasible.

Pratty (2024c) points out that there is recent evidence of some climate projects getting funded earlier than before by using offtake agreements. For instance, several European banks have been exploring the establishment of debt facilities to finance forestry projects ahead of anticipated carbon credit revenues. The author emphasizes that these findings represent a change from past lending practices, where banks were typically unwilling to fund projects without immediate revenue.

As discussed previously, offtake agreements play a key role in derisking projects by ensuring revenue certainty. Risks can be further mitigated through factors such as the reliability and financial stability of the offtaker, the level of commitment embedded in the agreement, and the specific structuring of the offtake terms. Next, these components are discussed further.

Reliability of the offtaker: Pratty (2024b) discusses offtake agreements in the context of FOAK projects. According to Pratty (2024b), investors typically assess the creditworthiness of the offtaker, as a financially stable and reputable buyer reduces risk. Offtakers are often large, established industry players, which enhances the perceived reliability of the agreement and, consequently de-risks the project.

Level of commitment: According to Pratty (2024b), FOAK offtake agreements can have different levels of commitment, ranging from conditional[5] to binding. The author highlights that conditional agreements can be sometimes converted to binding after certain performance milestones have been met at the FOAK project. According to the author, offtake agreements are demanded by more risk-averse investors. Commitment can also come in the form of longer time frame, as highlighted by Birshan et al. (2024). The authors highlight that one green hydrogen production project, the financing structure was secured with a help of a long term, 30-year offtake agreement with an international hydrogen producer. Further, Birshan et al. (2024) emphasize that this long-term offtake agreement played a key role in making the project viable by ensuring a reliable buyer for the hydrogen produced, reducing risk for financiers.

Structuring of the offtake agreements: According to Pratty (2024b), current FOAK offtake agreements are generally structured as one-to-one relationships, where a single offtaker commits to one solution provider. To mitigate risk, author suggests that offtakers can also commit to a pool of climate technologies. One example the author highlights of this type of structure is the Frontier Fund, where companies like Alphabet, Meta and McKinsey have committed nearly one billion dollars to support offtake agreements with carbon removal companies. Futhermore, offtake agreements can also come in a "take-or-pay" -structure, requiring the offtaker to either purchase and take delivery of the product or pay a specified amount to the project company (Climate Brick, 2024).

A well-known example of effectively navigating the 'offtake agreement' strategy is the Swedish battery manufacturer Northvolt. Volkswagen – Northvolt's largest owner – is also its largest offtaker, with plans of battery cells worth USD 14bn to be delivered over one decade (Billing, 2024b). In an interview made by Billing (2024b), Northvolt's former General Counsel Sofia Graflund talks about the role of offtake agreements in securing financing:

> *Strong offtake agreements attracted the financial investors we needed, and LOIs alone wouldn't have taken us all the way. Strong partnership agreements are, however, helpful even if they are not bankable. For Northvolt, we had strong commercial agreements in place from an early stage, and these had to be innovative due to lack of a mature product at that time, making the role of strategics again an important one. (Billing, 2024b)*

[5] Conditional agreements include Memorandums of Understanding (MOU) and Letters of Intent (LOI).

As discussed earlier, offtake agreements can limit the risks related to FOAK projects. However, even with solid offtake agreements in place, the project can fail. In September 2024, it was reported that Northvolt has urgent capital needs (Billing, 2024b). In October 2024, Ett Expansion – a subsidiary created for the expansion of the FOAK – filed for bankruptcy (Partington, 2024). Northvolt declared Chapter 11 bankruptcy in the US in November 2024 (Billing, 2024a). Northvolt's problems started to publicly rise in 2024, with the company admitting to problems within the scaling of cell manufacturing (Pratty, 2024d). Production delays led to BMW to pull out of a billion dollar order in June 2024, cancelling around four percent of Northvolt's order book (Pratty, 2024d). Northvolt has also been late to delivering cells to Scania (Lindeberg, 2024). Another example is Renewcell, Swedish textile manufacturer, that had solid offtake agreements in place before building their FOAK (Deppen, 2024). Renewcell filed for bankruptcy in February 2024 (Renewcell, 2024). As described by Tricia Carey, former Chief Commercial Officer of Renewcell:

> *We couldn't supply enough from the pilot line, and fiber producers really wanted this, and they signed offtake agreements, and they had LOIs. [...] We had offtake agreements that didn't come through for a variety of different reasons. (Deppen, 2024)*

These reflections highlight that, even with implied demand prior to the FOAK plant's operation and binding offtake agreements in place, significant uncertainties still remain regarding the actual demand.

Box 6: Offtake agreements in the FOAK context: Infinited Fiber Company (FI)

Infinited Fiber Company (IFC) has sold most of its FOAK's output for the first few years through binding offtake agreements with several customers, including H&M Group, Patagonia, Inditex, among others (Rantamartti, 2023). Weeks after IFC's competitor Renewcell went bankrupt, IFC closed EUR 40m financing round (Infinited Fiber Company, 2024). Reflecting on IFC's fundraising strategy for the FOAK, the CEO has stated that financiers are looking for well de-risked investments (Rantamartti, 2023) and that the company's fundraising strategy relates to selecting brands that have resources, size and capability of binding their operations into the future (Hernanz Lizarraga, 2023).

Table 4: Summary of emerged FOAK funding arguments over the whole literature review

	Rationale	
Capital source	**In favor of using as a FOAK capital source**	**Against using as a FOAK capital source**
Independent VC	High risk tolerance compared to other FOAK financiers; main source of capital for commercialization of radical innovations; specialized, larger and longer funds fit FOAK capital needs; non-financial assistance for FOAK startups	Climate FOAK characteristics: lower scalability of FOAKs, longer experimentation cycles of FOAKs, lower learning efficiency of FOAK lab experiments, limited return profiles (<10x) of FOAKs, large capital needs of FOAKs
Corporate VC	Can select greener ventures than IVCs; patient capital for FOAK projects; form of R&D for corporations; corporations have scaling experience which can help FOAK startups; narrative-building and innovation facilitation for FOAKs	Heterogeneity of corporate investors within cleantech; sharks dilemma between the FOAK startup and the corporation
Governmental VC	Bridging funding gaps related to FOAK stage; patient capital for FOAKs; de-risking, co-financing and catalyzation of private capital	Complexity of optimal GVC designs; case-specificity: key to understand optimal public policy mix; idea that 'government should not pick winners', such as certain FOAK projects over others
Private lenders	Aiding in capital costs and capital needs of FOAK projects; lower ownership dilution in FOAK projects; private, non-bank debt as less-risk averse FOAK capital	Low risk tolerance related to FOAK projects; still present technology risk not suitable for banks; higher interest rates for FOAKs (information asymmetry); commercial banks' regulatory and capital adequacy requirements do not support FOAK funding; lack of collateral in certain FOAK cases; non-specialized financiers
Public lenders	More risk-taking in FOAK projects; capacity to absorb losses; wider instrumentation spectrum for FOAK projects; larger ticket sizes for FOAK projects; de-risking, co-investing and catalyzation of private capital; bridging funding gaps related to the FOAK stage	Case-specificity: key to understand optimal public policy mix; idea that 'government should not pick winners', such as certain FOAK projects over others
Guarantees	Reduction of capital costs for FOAK projects; catalyzation of debt from private sources for FOAK projects; fiscal efficiency, specifically the context of novel technologies; de-risking FOAK projects	Case-specificity: key to understand optimal public policy mix; excessive availability of loan guarantees might lead to the funding of low quality projects
Grants	De-risking and catalyzation of private capital; bridging funding gaps related to FOAK stage	Case-specificity: key to understand optimal public policy mix
All sources	FOAKs require large-scale patient capital in the form of different capital types (equity, debt grants) and impact-driven financiers to manage the capital needs and risks associated with their development	

3 Qualitative study 1: Semi-structured interviews

This section aims to explore key constructs related to FOAK financing, focusing on conditions that influence the successful financing of FOAK projects. The section explores the current state of FOAK financing, including its perceived challenges and opportunities.

3.1 Methodology

The theoretical part of the study established that there is limited literature on the topic of the study, FOAK financing. Therefore, the first qualitative study focused on gathering information on FOAK financing. Interviews with professionals who work within FOAK themes were seen as a suitable way to gather this information. Gioia et al. (2013) method was seen fitting for data analysis due to its capacity to provide both depth and structure for inductive coding and theme development, given the scarcity of existing research.

3.1.1 Data collection

Following grounded theory (Corbin et al., 1990), the semi-structured interviews began with a broad objective to understand key constructs related to FOAK financing. The flexibility of semi-structured interviews allowed respondents to express their views freely. Several interview questions were deliberately open-ended to encourage discussion, given the novelty of the research topic. The interview guide was modified as the interviews progressed. Detailed interview guides can be found from the Appendix.

The final number of interviewees was 19. Two informants were interviewed for a second time, bringing the total number of interviews to 21. The number of informants was based on the theory of theoretical saturation, referring to "the point at which gathering more data about a theoretical construct reveals no new properties, nor yields any further theoretical insights about the emerging grounded theory" (Bryant & Charmaz, 2007, p. 611).

The interviewees were found through existing networks, desktop research and references from conducted interviews. Interviewees were selected based on their in-depth knowledge of the study's topic. Informants were located in the Nordics, with most of them based in Finland. It was prioritized that the informants presented different perspectives within the FOAK financing ecosystem, representing both different types of capital and position in the capital stack (e.g., public versus private and equity versus debt) and side of the transaction (e.g., capital provider versus startup). In-depth interviews were conducted from October 2024 to January 2025. All the interviews, except one, were conducted via Microsoft Teams/Zoom. The interviews were recorded and fully transcribed. A full list of interviewees is presented in Table 5. The findings section uses ID1 as the indentifier for the informant quote.

Table 5: Complete list of informants

ID1	ID2	Organization	Level	Instrument(s)
1	1	Corporate VC	Manager	Equity
2	2	Foundation	Specialist	-
3	3,4	Investment company	Head (Investments)	Subordinated debt
4	5	Governmental VC	Manager	Equity
5	6	Independent VC	Analyst	Equity
6	7	Climate tech startup	CFO	-
7	8	Bank	Manager	Senior debt
8	9,18	Investment company	CEO	Subordinated debt
9	10	Climate tech startup	Founder	-
10	11	Bank	Senior Banker	Senior debt
11	12	Climate tech startup	COO	-
12	13	Investment company	Director	Equity
13	14	Climate tech startup	CEO	-
14	15	Governmental agency	Chief	Grants, subordinated debt
15	16	Climate tech startup	CEO	-
16	17	Investment company	Director	Subordinated debt
17	19	Bank	Director	Equity, subordinated debt
18	20	Climate tech startup	CFO	-
19	21	Climate tech startup	Head (Finance)	-

Notes: ID1 = unique informant identifier, ID2 = non-unique interview number

3.1.2 Data analysis

The method of the analysis was inductive. Interviews were analyzed in the original language. The interview data was anonymized to respect the preferences of informants who wished to remain anonymous. The analysis of the interview results was performed using a grounded theory approach, enabling the review, organization and conceptualization of qualitative interview data (Gioia et al., 2013). Data analyzed by this method results in a "vibrant inductive model that is grounded in the data (as exemplified by the data structure), one that captures the informants' experience in theoretical terms" (Gioia et al., 2013, p. 8). Following Gioia et al. (2013), data analysis was carried out simultaneously with data collection, as interviews were transcribed, coded and iterated using Atlas.ti® software.

Open coding was conducted to identify descriptive in vivo codes, i.e., 1st order codes, derived from the informant's terminology (Gioia et al., 2013). The focus of this analysis step was based on catching each informant's perspectives of FOAK financing. As understanding around FOAK financing evolved, coding practices were modified to identify similarities and differences across data segments. Moreover, iterative coding was utilized by changing and merging codes. This process resulted in a large number of first-order codes, which through repeated reading and coding – iteration – were refined into first-order concepts. These were further linked into more theoretical concepts, as similarities and differences were analyzed to generate 2nd order themes. These themes described broader categories around FOAK financing structures. Emphasis was placed on emerging concepts that appeared to lack sufficient theoretical grounding in the existing literature, as well as on established concepts that stood out due to their relevance to FOAK financing. These are described by Gioia et al. (2013) as exhibiting 'optimal distinctiveness'. The analysis included continuous comparison and inquiry to raise the level of abstraction from second-order themes to overarching dimensions, as described by Gioia et al. (2013). The described process ultimately resulted in three overarching dimensions: FOAK capital stack, FOAK financing challenges and FOAK financing opportunities.

Finally, data structure was created from first-order concepts, second-order themes and aggregate dimensions. Structure allows visualization of data and a graphic representation of progression from raw data to first-order codes, second-order codes and aggregate themes (Gioia et al., 2013). The structuring process was iterative and its objective was theoretical grounding of the available data. The final data structure is illustrated in Figure 8.

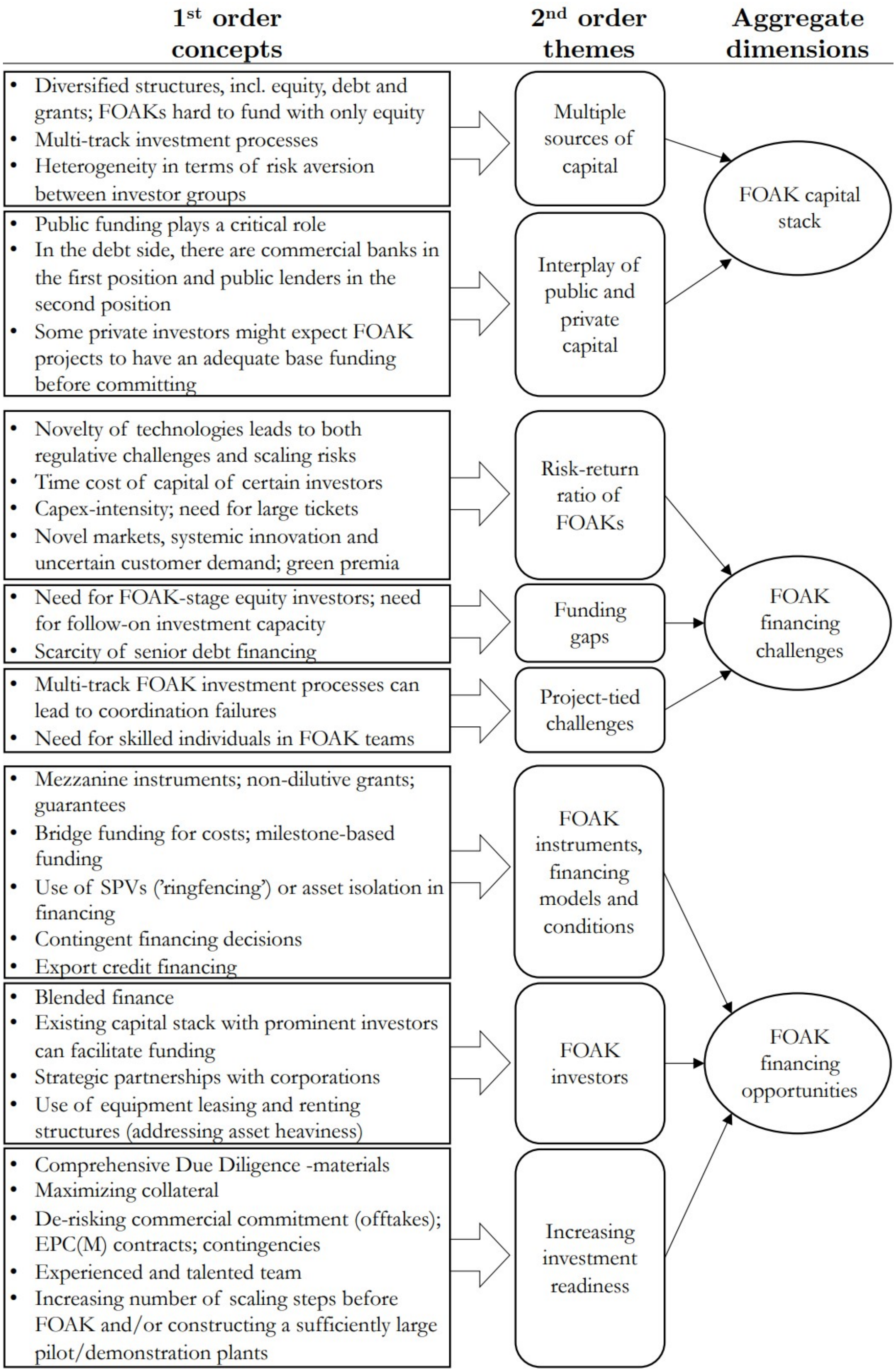


Figure 8: Data structure

3.2 Findings

3.2.1 FOAK capital stack

Before the FOAK-phase, capex-intensive startups are often funded with venture capital and grant money to build small-scale pilots that have investment costs of around a few million EUR. The capital needs increase significantly at the stage where the first larger-scale, commercially relevant plant – FOAK – is built. As the commercialization progresses, the share of debt financing increases. Grants are given by both domestic and European-level entities. Lenders include public and private financiers. Public lenders can provide subordinated debt in order to facilitate senior debt. In addition, public guarantors de-risk senior debt in the financing structures. Commercial banks' involvement is scarce. On the equity side, early-stage VC investors stay through the FOAK investment. Passive equity investors, like family offices, can act as co-investors. Lead investors can be, for example, larger specialist funds. The government is also a prominent financier in equity side through GVC. Traditional private equity investors are not involved in FOAK financing.

> *"Public loan financiers are clearly in a secondary position, while commercial banks are in the primary position, especially in Finland. [...] It's hard for me to say that there are significant subsidies missing from the market. It feels like if there's even a somewhat smart team and company with a business case, there were subsidies available." - ID2*

FOAK projects involve significantly higher investment costs compared to earlier scaling stages. As a result, they are challenging to finance solely through equity, and the smaller ticket sizes of typical VC investments are often insufficient on their own, with limited follow-on capacity. FOAK financing structures often involve multiple types of capital:

> *"[Talking about FOAK financing structures]: Biggest share is equity, then there is a bank loan and some grant support as well. [...] And the bank loan also has a [public] guarantee. This is probably the most common model how these [FOAK] cases are built. [...] Most of our FOAK investments have been done with on-balance sheet financing." - ID12*

There is heterogeneity among FOAK financiers regarding their willingness to take on different types of FOAK risks. This variation exists not only between different capital providers but also within similar groups, such as public lenders or private VCs. For instance, some thematic VCs may be more risk-tolerant than generalist VCs, and certain public financing institutions may have a mandate to take on greater risks than others public institutions in pursuit of a larger societal impact.

> *"Only a few [FOAKs] were able to obtain financing from commercial banks due to the risk involved. [...] [Commercial banks] were not involved in all the cases." - ID1*

"We take on quite a lot of risk our financing, aiming to fill the gap that banks don't cover. [...] However, we don't take on technology risk. Because if we were to take that on as well, our portfolios would become a bit too high-risk. [...] However, we do have a few exceptions where we have taken on [technology risk], a deciding factor for us is that [the plant] is of industrial capacity. [Our] investments aim to create impact." - ID17

"Compared to generalist VCs, we are definitely a high-risk investor. [...] We leverage our network when our own capacity isn't enough to validate [the technology]." - ID5

As different parts of the FOAK plant can be financed with different mechanisms and financing sources can be mutually dependent, fundraising efforts will need run in parallel. One lender pointed out that this parallel nature can lead to challenges, such as lack of focus, uncertainty and additional work:

"One major risk is that there are multiple overlapping simultaneous processes underway, which can cause the focus to be lost. [...] In many of [project-financed FOAK cases], it often seems that a certain level of lender commitment is expected before equity is committed. This is the opposite of how things have traditionally been. [...] Projects are essentially still being developed while commitments are already being sought from banks. In other words, the project finance process has, in a way, been turned upside down—at least partially. [...] This creates a degree of confusion, overlaps, and, in a way, additional work. From the lender's perspective, these processes haven't become any easier—quite the opposite." - ID10

Both the use of on-balance sheet and off-balance sheet financing were seen as ways to finance FOAKs. There was different opinions between financiers on which of these funding models is the most commonly used. In off-balance sheet financing, special purpose vehicle ('SPV') structures can be used. These SPVs contain certain assets that are related to the FOAK plant investment. If all of the valuable assets are located in the SPV, lenders can effectively 'ringfence' these assets. Ringfencing de-risks the investment through asset protection:

"I think SPV structures are an important element in FOAK financing due to the idea that you can isolate the risks in other juridical entity. [...] All of the valuable assets are in this entity ('SPV') and lenders and ringfence the SPVs assets to themselves." - ID2

"In terms of numbers, I'd dare to guess that there are probably more FOAKs in SPV-type or project-financed models than in balance sheet-financed or corporate finance-financed models. The advantage of this is that a project can potentially get started even if the owners don't have the money—that's essentially what it boils down to." - ID10

One informant talked about structural subordination. The informant noted how sometimes these complex structures can involve a parent company, operative company and several SPVs (with the operative company under the parent company and the SPVs under the operative company). Risks might be distributed between the SPVs so that assets and financing are in different companies. As a lender, you need to make a decision on which entity you will finance. This involves observing where everyone else is going and then finding a suitable place for yourself. The informant concluded that most lenders want to minimize downside and go to the SPV.

> *"Generally, it is done through project financing, and if there are good professionals handling the project financing, there are proper guarantee structures in place, so the risks aren't extremely high. The idea here is that the financing is channeled to the SPV instead of going to the parent company, as financing the parent company is very risky, of course. However, there would be significant risks if one were to go to the parent company while others were in the SPV. The structural subordination always needs to be considered carefully in project financing. [...] There is always a risk that if some of the assets are in the parent company, the parent company's creditors get back the money before you. [...] You need to be really focused on the specific details in the case of bankruptcy/liquidation." - ID2*

Project finance can enable smaller companies to access significantly larger resources by isolating financial risk without impacting their balance sheets. One startup reflected the use of SPVs:

> *"SPV is just a tool, way to finance – nothing else. It helps the balance sheet of the startup. [...] However, financiers need to get upside from it, and how you build it there can be often difficult" - ID9*

Selecting between off-balance sheet versus on-balance sheet financing can depend on several factors, such as exit strategy considerations. Startups must plan for potential exit strategies, such as selling the parent company (including its IP and subsidiaries) or selling individual production facilities. If the production facilities are planned to be sold separately (and the technology licensed), SPVs can be set up to simplify potential transactions. Moreover, if the business model involves licensing the technology, it is also crucial to establish clear boundaries between the parent company and facility ownership through the use SPVs.

> *"Most of our FOAK cases utilized project financing. [...] In many of these FOAK concepts, there is a structure where you have a parent company that holds the IPRs – such as patents and know-how – along with related rights. Then, you have structured the FOAK plant into a separate subsidiary. [...] The SPV has a specific cash flow profile that is tied to the sales and operational activities of that individual facility. [...] [That SPV] can be structured as a project financing case that generates cash flow, which can be used to pay off certain loans tailored to that specific facility. However, the expected ROE for*

> *that individual SPV is not very high. [...] In contrast, the parent company has a much higher expected return and can be viewed as more of a scalable business." - ID3*

One informant reflected that project finance can work better more generic products (e.g., electricity). However, project finance model may not be ideal for businesses where IP is the core asset, which might be the case for many FOAKs:

> *"In my opinion, SPV structures should be used in situations where the product is very generic. You can compare it to electricity production, which works well for SPVs since there is not a large IPR component attached to it and you get a certain yield. But if you think about certain FOAK startups, the IPR might be tightly tied to the used process." - ID12*

3.2.2 Perceived FOAK financing challenges

One of the emerged fundamental problems of FOAK financing is that their risk-return profile often fails to align with the criteria of many financiers, particularly those in the private sector. This leads to FOAK-stage funding gaps. Risk-return ratio of FOAKs is a result of high risks (especially market and technology risks), unclear return potential, capital intensity as well as longer development timelines.

Often identified FOAK financing challenges included risks related to underdeveloped markets, including risk arising from value chains, green premia and offtake risk. Many financiers across the FOAK capital stack agreed on the market risk being the largest FOAK-specific risk. Informants highlighted that the goal is not simply to manufacture a product, but to ensure that once the technology and process have been made functional at a certain scaling level, there is sufficient market pull to justify the production of larger quantities. Some financiers refrain from investing in FOAKs that have not demonstrated their technology to a certain extent, while others are more risk tolerant, indicating a varying risk appetite among capital providers. One informant highlighted how FOAK risks can not be generalized because they vary depending on the sector:

> *"I don't think you can generalize [FOAK] risks from highest to lowest; all of the risks are present, but they are somewhat industry-specific and segment-specific. For example, in some cases, raw materials completely dictate the process; in others, the process itself is the key factor, and in yet others, the end-product market drives the process. These can also vary slightly across different geographic regions." - ID12*

After market risk, technology and financial risks were mentioned frequently, with the technology risk being often mentioned as the largest risk after market risk. The informants highlighted that there is always some technological risk when moving to a commercial scale which has not attempted before:

> *"Based on our experience, both the technological risk and the risk related to the*

commercialization/market risk are the two biggest risks." - ID17

Financial risks included, for example, inadequate financing plans, weak returns as well as insufficient additional funding. Several informants highlighted large cost overruns in FOAK projects, highlighting the need of contingency reserves:

> *"We have seen a lot of cost overruns in FOAK projects, depending on the case. There has been 50 percent cost overruns in the capital expenditures, etc. [...] You need to have buffer in the budget for those. They differ a lot based on if you are looking at a FOAK plant or a standardized technology." - ID3*

> *"It's very typical, and challenge with FOAK projects – that even though it might look fine in an Excel sheet or on paper beforehand, the lesson learned for me is that you need to account for double the costs to truly understand the situation. You need to know where the pain threshold is, beyond which this will no longer be a viable business, and we won't get anywhere. Typically, a FOAK investment involves very expensive learning costs that have to be paid. [...] We learned that even though [well-established engineering companies] might have done the specs and drawings, they often provide a range – say something like, plus or minus 5%, 15%, or 25% – those estimates simply aren't accurate. The [FOAK plant] costs end up being much higher." - ID8*

It is also important to note that some of the situations reflected by the informants occurred during external shocks, such as the pandemic and the war in Ukraine. Some FOAK plants may have been planned and committed prior to these events, only to face disruptions during the construction phase. This also highlights the effect of external environment on FOAK financing.

Since most FOAKs operate in underdeveloped markets, accurately estimating their financial returns is challenging. Furthermore, technological risks can result in project failure even before the product reaches the market. FOAK projects are capital intensive, amplifying the stakes as potential failure can mean significant losses for the capital provider. Especially private investors may struggle to see how the FOAK project's potential upside justifies its high risk. While venture capitalists are characterized as high-risk investors, traditional VC firms may shy away from FOAK projects because their funding models favor scalability and high returns within shorter time frames. The capital demands and inherent risks of FOAK projects often exceed the smaller ticket sizes that are provided by venture capitalists, and VCs may also lack the needed follow-on financing capacity for FOAKs:

> *"You can definitely see that many VCs are allergic to these capex-intensive cases. The thinking is that the upside you can achieve, in relation to the type of business model you have and how scalable it is, is considered to be smaller. [...] [In the context of larger scale FOAK plants] we need a financier that can provide larger tickets (e.g. tens of millions of EUR) with follow-on capacity. That we do not currently have." - ID5*

The time cost of capital may make venture capitalists hesitant to invest in capital intensive climate hardware, which typically requires longer development timelines compared to options like climate software:

> *"In projects like these, the absolutely essential thing is to get the project off the ground, rather than ensuring returns on equity. I understand that if there's, for example, a fund or any other investor, they naturally want returns on their investment. [...] But I think this should be viewed more from the perspective that once you achieve that FOAK, it then serves as proof that the technology works, and the returns should then be based on its scalability rather than necessarily aiming for huge equity returns within the first five years. [...] There should be a longer-term perspective. But I do understand that there are different types of capital, and some are more impatient than others. However, in that case, you can't blame lenders for not taking risks if even the equity investors aren't necessarily willing to take risks." - ID10*

Continuing on the topic of limited investor appetite, several risks associated with novel technologies employed by FOAKs are often seen as the reason why commercial banks avoid FOAK financing. One informant explained the situation in further detail:

> *"[FOAKs] are such concentrated risk areas from a bank financing perspective that these types of cases can't even be handled outside of specialized units. They push every risk indicator so far into the red that no one wants to engage with them. It's exceptionally rare to take on such projects, and in regular banking — outside of these specialized units — it requires an individual-level risk acceptance that overrides systemic risk signals, accepting a significantly higher level of risk for a given project. That's why it's so challenging for these players to secure bank financing." - ID7*

From the bank perspective, lenders say they cannot be the main risk-bearers, but a smaller part of the solution. The interviews highlight that the involvement of banks calls for innovative structures. One possible model for commercial bank involvement is bridge financing. One of the interviewed startups had a situation where a granted subsidy was given based on the actual costs that have incurred, requiring a significant amount of working capital.

> *"Banks can bridge those kinds of instruments so that the company doesn't have to burn their equity during the project. Instead, banks can provide them with a working capital solution that can be safely bridge against such an instrument, as long as banks have confirmed knowledge that there's commitment to it and, you know, ten million or so is coming. Yes, banks can do things like this." - ID7*

Another model for commercial bank involvement is export credit financing:

> *"Well, then there's the aspect of someone providing a guarantee, from entities such as export credit agencies. For examples Swedish startups have successfully*

chosen suppliers strategically to ensures that export credit agencies from other countries come in to guarantee loans, enabling the export deals with involvement from multiple export credit agencies." - ID8

Maximizing collateral can also facilitate commercial bank involvement:

"What alternatives do banks have if such guarantees aren't available? That's where collateral comes into play. The collateral can sometimes come from the secondary market for the capex investments. For instance, when it comes to buildings, the situation can vary greatly. If you are constructing a highly versatile building that can be rented out for other purposes and is in a suitable location, then that's a significant advantage." - ID8

Finally, commercial banks can de-risk investment through asset isolation. Here, the bank isolates the specific asset being financed (e.g., equipment) from the broader project (e.g., the entire factory). This reduces risk by limiting exposure only to the value of the isolated asset, rather than the entire FOAK project or company:

"Financing needs to be isolated, and by isolation, I mean that instead of financing, say, an entire factory, you could finance a specific part of it. For example, you could create a working capital financing solution. For example, you can finance the equipment directly. That means you don't touch the walls; you didn't get involved in the construction project. You don't deal with those aspects in any way; instead, you finance a clear, specific asset within the overall setup." - ID7

The interviews highlight that many financiers see the urgent need for scaling climate technologies and, thus, climate FOAKs:

"Perhaps the challenge is that it often takes years, even decades, to figure out how to do this optimally, while in the bigger picture, we should keep the climate challenge in mind and focus on pushing these projects forward with speed." - ID8

"When it comes to green transition cases, there's also the [the larger] impact that scales alongside these capex investments [compared to software cases]. More and more funds are now these Article 8 and 9 funds, where having impact is a requirement." - ID5

"These are truly fascinating cases, and we'll definitely look at whether we can get involved and fund them. But the structures make it so complex, which brings up the issue of public funding availability that I've mentioned before. That [public funding] is the main driver here." - ID7

However, the results of the interviews highlight that there are funding gaps for the FOAK stage. As suggested before, several investor types find the risk-return ratio of FOAKs insufficient, leading to limited investor appetite:

> *"It would be really important to have proper [large enough] pilots where the production technology can be tested, and for those to be funded by someone, because that's clearly a [funding] bottleneck. Nowadays, no one really funds that, except for VC firms, which are the ones willing to take a bit more risk." - ID17*

While venture capital firms can take on more risk, the required returns and capital needs often do not align with their fund strategies or sizes:

> *"But then again, is [the FOAK] truly a VC case? Is it one where you can get at least a 10x return on your investment? Those are pretty rare." - ID5*

> *"[FOAK financing] is quite a complex task, because the combination – the risk and capital requirements [of FOAK projects] – is such that it doesn't really fit anyone's domain. [...] [FOAK financing] offers a challenging proposition for traditional infrastructure investors – there's a bit too much risk involved, and for traditional VC investors, there's a bit too much capital expenditure." - ID4*

Moreover, some informants suggested that FOAK funding gaps are also an inherent part of growth financing. FOAK presents a high risk investment, and investors may be unwilling to commit large amounts of capital or they may demand higher returns to compensate for the FOAK risk, reducing the overall available capital. In addition, some companies simply fail to meet the necessary criteria for investment:

> *"There is still, despite our efforts, a funding gap, because there are, of course, these risk elements present. [...] Risk and return are always closely linked. [...] In a market economy, these elements can never be completely eliminated." - ID12*

> *"It is generally said that many companies should get more money. You can have different opinions on that, because not all ideas are worth investors' money. It is noteworthy, that once the risk-return profile is suitable, they can, indeed, get the money." - ID4*

While several informants see that there is urgent need to scale the technologies, not many are willing to be the risk-taker, resulting in funding gaps in the FOAK stage. According to the interviews, private capital appears unwilling to bear the high risks associated with FOAK projects alone and requires the involvement of a public component. Recently, some climate projects have attracted large amounts of capital. One informant highlighted that there is, indeed, money in the market, but you need to find mechanisms to de-risk it for it to participate in FOAK financing structures.

> *"Well, if you look at Northvolt and H2 Green Steel, there's definitely money available. Both are FOAK-type projects, but they've poured billions into them, so in a sense, the money is there. [...] But it's clear that there's more capital available for the second project than for the first one." - ID10*

> *"There is money on the market for these investments, you just need ways to de-risk it." - ID2*

> *"Well, the biggest problem here is that there really aren't any investors for this phase. When you're fundraising on this scale, you usually need to show some track record of sales. But you can't have those if you're building your first factory. You simply can't have realized sales – it's just not possible. You need the factory first. The investors for this phase, the ones who would fund factory projects, are generally only interested in the next phase." - ID13*

Another informant highlighted that large climate projects such as H2 Green Steel (now Stegra) and Northvolt have received significant amounts of several forms of public support partly because they could not secure the necessary financing on market terms. Moreover, governments also pursue their own objectives: green industrial projects contribute to achieving climate targets and enhancing national competitiveness. As a result, countries may compete to attract large-scale projects in the form of subsidies. Due to private capital's unwillingness to bear the risk, almost all informants agreed on the importance of public support. Public financiers, however, balance with the additionality of their funding:

> *"Currently, there are no investors in Finland who can write very large tickets for late-stage funding rounds. Public funding can close that gap. But that doesn't solve the problem in any way – the catalyzing of private capital and attracting private investments is still absolutely essential." - ID4*

> *"You want to be very careful in ensuring that our financing goes towards areas where state intervention is justifiable. [...] Public and private financing are not exclusionary. [...] When it comes to public funding interventions, the question often revolves around which instruments can be used to mobilize as much private capital as possible." - ID8*

During the time of the interviews which were conducted in late 2024, draft of new investment strategy of Finnish Industry Investment (Tesi) was released. This included a proposal to make the number of direct investments five times larger than before. Proposal received several statements, including one made by Finnish Venture Capital Association (2025). This draft for the new investment strategy received mixed reactions among informants: one informant expressed concern around how de-risking direct investments are and whether Tesi possesses sufficient capabilities in impact analysis and project financing. Another informant saw it as potentially positive, suggesting that Tesi could take on the role of a lead investor — something that FOAK projects often struggle to secure, hindering fundraising processes. A third informant said that if Tesi's direct investments fill the gap needed for the financing of larger-scale facilities – which has been a bottleneck in Finland – it sounds positive. On the other hand, the same informant questioned whether a larger fund dedicated solely to deep-tech could fit the role better, in contrast to Tesi, whose investments are more diversified. The informant also raised a point on whether state-affiliated direct investments might hinder foreign investment.

Novel technologies are often heavily impacted by the political and regulatory environment. Positive developments in these areas can be 'make or break' moments for many FOAK projects. Many informants highlighted how regulation should be made with a more long-term view:

> *"It's really important for the consistency of policy, particularly regulatory consistency, that it should be long-term. Any uncertainty in either direction makes it incredibly difficult for investors and for us during project preparation. You always have to base everything on a set of assumptions about how these new markets are developing, which almost always relates to FOAK projects as well." - ID8*

> *"Regulation should enable projects, and it should be sufficiently secure from the perspective that they are long-term. [...] Or that the regulation supports long-term decisions. Additionally, the entire system should be oriented in such a way that, for example, gray hydrogen is not the way forward but rather the system is forced into making green hydrogen production actually reasonable—in other words, making it feasible. The process involves defining what this entails, for instance. And after that, the system is then directed to support this approach. In my view, that's the silver bullet, if such a thing exists." - ID10*

> *"[If the risk-taker is] the government, then it becomes political and changes are quite slow. [...] [Political decisions] can completely turn the market around, and these are the factors that increase the uncertainty about what's going to happen; visibility is really the key." - ID2*

3.2.3 Perceived FOAK financing opportunities

The interviews revealed a set of actions grouped as FOAK financing opportunities. This set of actions is further categorized to two categories: 'catalyzing and derisking FOAK investments' and 'increasing investment readiness'. The first category refers to actions both financiers and startups can do and what financial structuring can achieve, and the latter refers to actions startups can take themselves.

Catalyzing and de-risking FOAK investments

Large investment stacks, milestone-based financing, mezzanine financing/subordinated loans, use of guarantees and blended finance were brought up as ways to catalyze and de-risk financing for FOAKs.

> *"I've been thinking about [derisking FOAK investments] for a long time. [...] What it ultimately boils down to in the finance sector is that we need someone who actually takes on risk. Someone who has enough of an impact angle and sees a potentially big upside. [...] If the investment fails, it would be seen as, well, hey – it was essentially a grant. The idea is that it would enable taking on more risk, and someone needs to be the catalytic financier who takes that risk. [...] If it's a foundation, a family office [...] or some other impact-driven [private] actor, I think there lies power there — they really do move the money." - ID2*

> *"It naturally depends a bit on the type, but there should be state support for these kinds of transition projects for a certain period of time. However, as with wind power, for example, it no longer needs support nowadays, and perhaps soon the same will apply to solar power." - ID10*

> *"[Mezzanine instruments] have been seen as catalysts for other financiers, such as lenders. [...] Also, when you've ensured that certain things must happen before the next financing installment, [milestone-based financing] becomes an important risk management tool in my opinion." - ID1*

> *"Well, as far as I'm concerned, it doesn't matter whether it's subordinated debt or equity-like debt—in terms of the lenders' perspective, it makes no difference. [...] In fact, quite the opposite; if it's equity, it might even be better." - ID10*

Different investor and capital types can trigger further investment:

> *"And then finally, how [the financing of the FOAK] was resolved was that there was this loan instrument that was relatively advanced, and then this grant was found, and then we were negotiating equity financing. So we were progressing on three different fronts. And then what ultimately triggered it was that one equity investor made an investment decision, which then got the lender to move and provide the loan. That was how the equation was solved." - ID6*

> *"Without [public grant instrument], we likely wouldn't have been able to raise the capital for the facility at this early. [...] However, this support significantly accelerated the process and made it possible. It also attracted both existing investors already involved with the company and new ones. The opportunity presented by such substantial support, provided we could gather the equity financing required as a condition, was very appealing. So, this public support fully enabled the funding round." - ID11*

Guarantees were identified as an effective mechanism to mitigate investment risks for senior lenders. In some cases, the size of the guarantees was deemed insufficient by commercial banks, which often required entrepreneurs to demonstrate commitment by having their own 'skin in the game'. Many informants highlighted guarantees as a crucial factor for securing senior loan participation, with some describing commercial bank involvement as unfeasible in their absence.

> *"When we consider the share of debt, [guarantees] certainly had a significant impact. [...] They were crucial for obtaining such a bank loan." - ID6*

> *"Public investment agencies that offer guarantees have been looking at some of our FOAK cases. [...] But if the commercial bank is not interested for one reason or the other, the guarantor does not have a role." - ID3*

One informant talked about ways to structure upside into the loans:

> *"But in my opinion, even if it's financed by a loan, it's worth considering how to structure the upside into the loan. For example, [one Nordic fund] uses a kind of equity kicker, where if the valuation increases by 5x, it converts into equity, allowing you to capture the upside. In this case, it would be beneficial to be in the parent company [in the SPV structure]." - ID2*

A need for an equity fund was brought up both by startups and financiers. IVC-informant saw need for a FOAK investor that could put larger tickets – those in the scale of tens of millions – to larger scale FOAK facilities, and also have capacity to put follow-on capacity later on, since this type of investor is missing from Finland. This investor could for example be a later-stage VC fund or even an evergreen fund. Further, a commercial bank informant saw a need for a larger equity investor, as there are currently only few players large enough to join later-stage rounds. The informant noted that there is currently a fundamental question regarding whether rather than having smaller equity funds, there should be fewer larger funds capable of handling early-stage investments while also having the capacity to support FOAK projects through later stages. One startup, in particular, encountered absence of equity investors while fundraising for their FOAK. The CEO explained that the key bottleneck in fundraising had been the availability of equity, and that the startup had gone through a significant amount of equity investors before unlocking equity financing:

> *"We went through a significant amount of equity investors so we put in a huge amount of effort. It's an enormous job to raise capital, absolutely insane. There just aren't [equity] investors for this phase." - ID13*

Ultimately, the startup was able to secure a few million ticket from a VC fund, which was consistent with the typical VC investment seen in the studied FOAK financing structures.

Increasing FOAK investment readiness

Several ways for FOAK startups to increase their investment readiness, and thereby, catalyze financing were identified. A long list of these actions includes contingency reserves (i.e., funds reserved to cover unexpected costs related to the construction of the FOAK plant), comprehensive and shared due diligence, credible customer pipeline, use of equipment leasing, EPC(M) partners, the size of the scaling step as well as technological demonstration before the construction of the FOAK in the form of a smaller scale demonstration plant. Modularity of the technology can also mitigate technological risks. One informant highlighted how addressing the risks – mentioned in Section 3.2.2 – can effectively increase investment readiness:

> *"The methods that mitigate risks are the most essential aspects [in increasing investment readiness]. [...] [These include] offtake agreements, raw material or feedstock agreements, permits, EPC(M) models. These are exactly the kinds of things that mitigate the risks investors want to see addressed. [...] Another key factor is collateral. [...] Also additional financing, especially since we've seen so many cost overruns in these projects. [...] So, where does the additional financing come from? Are there stakeholders involved in the project who can provide the necessary extra financing for the company if needed?" - ID3*

Offtake agreements were mentioned often as the key way to improve investment readiness. In addition, contractual assurance for the feedstock, i.e., the raw materials used in the processes were mentioned as well:

> *"[Contractual commitment] has been the critical factor [...], and it usually requires a two-way approach. That is, it concerns both the incoming raw materials and the sales of the outgoing products. So, it's a dual requirement. Because of this approach, one of the most important things has been the commercial validations for both the incoming material and the outgoing material. This has been the critical pivot point for us, enabling the arrangement of various financing options." - ID15*

> *"I would say that the offtake is kind of the biggest [condition]. [...] If you can secure an offtake that is long enough — whatever that again means — and on sufficiently good terms, then it's pretty much at the core of [improving FOAK investment readiness]." - ID10*

Increasing investment readiness can be achieved through technological demonstration, as previously mentioned. One of the key risks identified for FOAK projects is technology risk, which can be mitigated by implementing additional scaling steps and/or by reducing the scale of the transition from pre-FOAK (such as subscale pilots) to FOAK (commercially relevant plant). A technology risk-averse lender noted that technology risk can be reduced when the technology is demonstrated in a larger pilot or demonstration plant before reaching a commercially viable FOAK stage.

> *"It would be really important to have proper pilots where the production technology can be tested." - ID17*

> *"Do we first build a less expensive, non-cash-flow-positive facility that can better demonstrate the technology, which costs less and might be easier to finance? Or do we go straight to a truly commercially viable scale, which can come with a lot of risks related to whether the operation will run smoothly and whether everything can be sold. [...] It's surely very case-specific and industry-specific as to what makes sense to do." - ID1*

Offtake agreements were mentioned often from investors. However, some startup representatives said that getting offtake agreements can be hard and the easiness of obtaining them can also largely depend on the industry.

> *"Often in these FOAK plants, prospective portfolio companies have commented that it's a chicken or the egg -problem. [...] [From the startup perspective] you need to have the plant to get the offtake agreement, and then the financiers say that you need to have an offtake agreement to get the plant up and running. So it's quite complicated." - ID3*

> *"You can not get [offtake agreements] to FOAKs. [...] If you have a customer and your FOAK supplies [certain renewable feedstock] and the customer needs 100 units of it. And you have a FOAK that supplies 5 units of it. OK, you think that of course I can buy 5 units from there. But what if it does not work, because it is a FOAK? [...] So they need to do some protection mechanisms in case they need it someplace else, it is going to cost. No one is going to take risk in that sense. You need to get it in a way that the feedstock has been tested and proven." - ID9*

> *"And this, in a way, brings up what is typically what I myself think is the issue with financing FOAK facilities. So the challenge is that it's hard to secure the commercial side and offtake agreements, when there is no production, and it's impossible to gather the capital for a production facility investment if there are no offtake agreements, so you end up stuck in that kind of loop." - ID8*

> *"This also varies a bit by sector. [...] We notice that in very basic commodities like wind power, battery capacity—things like that—the financing feasibility might be somewhat easier in some ways because the contracts and the commercial operating model are simpler than, for example, in our use case. There, the offtake agreements you mentioned are made much more frequently and at earlier stages, making it easier to finance. On the other hand, in sectors like [our operating industry], offtake agreements are not as common. [...] Thus, the role of subsidies is more significant and important for the project to succeed." - ID6*

The EPC(M) model was introduced as a way to reduce investment costs and de-risk the FOAK investment. According to OCED (2024), traditional project development focuses on de-risking the project through external partners, such as signing a fully wrapped engineering, procurement, and construction (EPC) contract with an established EPC firm. One FOAK financier reflected on that only EPCM model (instead of EPC) had been used in FOAK cases. In the EPCM model, the contractual responsibility stays with the project company itself, suggesting that FOAK projects are seen too risky by the EPC firms:

> *"The problem with FOAK plants is that the EPC model doesn't work well. Since such projects have rarely, if ever, been implemented before, there are usually no EPC providers willing to take on the risk. If a provider does agree, they set such a high price that no one can afford it." - ID3*

Finally, the importance of team was highlighted. Some informants reflected that one FOAK specific challenge can be that FOAKs are often run by founders, and while they may have a deep understanding of the product and technology, there may be a lack of resources in commercialization efforts. For example, some founders may believe that the product will 'sell itself' or that deep historical involvement in the product's development is needed for successful sales efforts. One informant said that this problem might also be due to lack of resources for hiring new talented individuals to the organization to, e.g., lead the commercialization efforts.

> *"The team is, of course, extremely important. Do they have all the competencies needed for growth? Are they the kind of people who can raise the necessary funds and, on the other hand, sell the product? That has an enormous impact on how quickly the project can come together." -ID1*

> *"Ultimately, the decisions about moving forward with a project often come down to the quality of the project preparation. It's about selling, marketing, persuading, and convincing—much of it depends on whether the project preparation team is seen as credible. A lot hinges on whether there is a truly credible team with extensive experience in scaling operations like this and a strong track record of repeated success." - ID8*

Furthermore, one informant emphasized that the FOAK team must be capable of navigating the policy dimensions effectively:

> *"Having a strong team in the background with individuals who know how to commercialize is even more emphasized in FOAK projects. [...] On top of that, you also have to think about the policy aspect. I'd say the ideal person for this kind of role is someone you can trust to get the job done, someone other stakeholders can trust, and someone who can communicate not only expertly within their own field and to financiers but also effectively in the political arena." - ID2*

4 Qualitative study 2: Multiple case study

This section builds on the first qualitative study to answer the research question: What conditions contribute to the development of successful FOAK financing structures?

4.1 Methodology

In order to answer the research question *What conditions contribute to the development of successful FOAK financing structures?* multiple case study was chosen as the research method. Given limited theory and evidence on how FOAK financing structures are closed, inductive theory building was used with a multiple case study (Eisenhardt, 1989), which enables building both more robust and generalizable theory (Eisenhardt & Graebner, 2007).

Optimal entrepreneurial outcomes, such as securing funding for a new facility, are typically contingent on combination of factors, suiting a configurational approach. For many new ventures, such as pre-revenue FOAK startups, there is a lack of prior accomplishments, and the market demand for their output remains unverified. In the face of uncertainty, capital providers encounter significant challenges in assessing the return potential related to prospective investment, relying on signals which indicating venture potential (O. Colombo, 2021; Islam et al., 2018). These signals can include, for example, government grants (Islam et al., 2018) or technological capabilities (Fisch, 2019). Prospective investors encounter a range of these signals and typically assess a venture holistically instead of evaluating such signals individually (Svetek, 2022), and the signals can be seen as different configurations, each leading to same outcome, i.e., securing investment (Edelman et al., 2021). As pointed out by Topaler and Adar (2025), examining this complex phenomena calls for configurational approach. Two questions were examined using the cases. The first one considered the interaction of different financing elements:

> ***Q1:*** *Is the outcome – successfully closing funding for a FOAK plant – a result of an interaction between multiple elements in the FOAK financing structure, rather than a result of isolated financing elements?*

Following this question, examined FOAK financing structures are analyzed based on how specific combinations of conditions interact to produce an outcome, successfully closing funding for a FOAK. Rather than focusing on individual factors in isolation, this approach emphasizes the interdependencies between multiple conditions within a financing package. The financing structures can include both necessary and sufficient conditions. A condition is necessary if it must be present for the outcome, i.e., successful close of FOAK financing package. A condition is sufficient if its presence alone can produce the outcome. For example, public funding might be necessary (a precondition for private investment), but not sufficient on its own (making FOAK fully funded also requires private sector engagement). Furthermore, the analysis also considered the different paths to outcome:

> ***Q2:*** *Are there multiple configurations of conditions that can lead to a successful close of a FOAK financing package? In other words, can FOAK startups utilize different strategies to make the plant fully funded?*

Following this question, different paths to successful outcome were examined, analyzing evidence on whether multiple configurations can lead to the same outcome. For instance, different mixes of public and private capital might lead to a successful close of FOAK financing package. This question also guided the writer to find different 'FOAK archetypes', different startup strategies for closing the FOAK funding.

4.1.1 Data collection

The studied cases were identified through a combination of existing knowledge, desktop research, FOAK investors' investment portfolios and informant recommendations. All selected companies are climate technology startups and the studied plants fit the definition of FOAK described in Section 1.5.1. The interviews focused on having a primary informant who was a key representative from the startup, such as co-founders and/or C-suite executives, as these informants were most directly involved in the fundraising process and offered the most valuable insights. Secondary informants include FOAK financiers (debt, equity and grant providers) who either agreed to discuss the specific case or, while not directly commenting on the specific case, shared insights into their FOAK investment strategies which still aided in understanding their investment rationale. The final set of cases and interviews are presented in Table 6. These interviews overlap with the interviews in Section 3.1, as all of the interviews that are presented in Table 6 are also included in Table 5.

Table 6: Primary data sources for the case study

Case	Total number of interviews	Primary informant	Number of interviews with FOAK financiers
Vanguard	3	CFO	2
Pioneer	4	COO	3
Wayfinder	2	Founder	1
Trendsetter	3	CEO	2
Trailblazer	1	CEO	0
Forerunner	2	CFO	1

4.1.2 Data analysis

The main idea behind the data analysis was that the interviews with startup informants helped to find configurational patterns in financing structures while unpacking the causal mechanisms underlying them. The key mechanism for this is analyzing the descriptive data (elements of the financing structure that are derived both from primary and secondary data) and mirroring it to comments of the startup. These comments helped explore certain 'catalyzing conditions' that are likely to explain the identified configurations of conditions and how they are connected to the outcome, i.e., successful close of FOAK financing package. Catalyzing condition is defined as the necessary condition required to successfully close the FOAK funding in a specific case. For example, the configuration 'senior loan recipients' included cases that had received senior loans. In-depth interviews were able to capture set of catalyzing conditions that lead to receiving the senior loan, such as public guarantees. The data analysis for the case section was done in four steps which are described below.

Developing conditions: To understand what elements constitute successful financing structures, the data from the first qualitative study was analyzed following the methodology described by Gioia et al. (2013). In the interview data analysis process, first-order codes were synthesized into second-order themes, which were further aggregated into overarching dimensions. This process is further described in Section 3.1. The coding methodology allowed systematical search for conditions of successful financing structures by breaking available qualitative data into codes and themes. The iterative process identified several key conditions, such as public grants, offtake agreements, leasing/rental arrangements and guarantees. The conditions were iterated across the process as some cases brought up conditions.

Performing within and cross-case analysis: Following Eisenhardt (1989), within-case analysis was conducted to all cases, including detailed case write-ups. Before every interview, the case was thoroughly analyzed based on secondary information. This analysis included descriptions of FOAK funding timeline, FOAK capital providers, FOAK financing structure and other relevant funding information. Company and investor press releases were found to be a great information source, complemented with other information, such as databases (e.g., Pitchbook and Preqin). This pre-analysis allowed the writer to identify information gaps and potential questions for the upcoming interviews. Following Eisenhardt (1989), within-case analysis was combined with cross-case analysis to seek out patterns between the cases. Several tactics were employed to identify cross-case patterns. The data was organized in tables with cases represented in rows and conditions in columns. These case comparison tables represent an essential part of qualitative comparative case research Eisenhardt (1989). A case comparison table was kept up-to-date for each case to ensure easy cross-case data examination. This step allowed capturing in-depth account of cases and identification of similarities and differences across cases, aiding in emergence of patterns. The results of this analysis step are shown in Table 7.

Incorporating 'catalyzing conditions' from interview data: The configurational approach required a method to classify the conditions into necessary and sufficient categories, and to study how conditions interact to produce the outcome, successfully closing funding for a FOAK plant. The interviews revealed specific moments or elements in the fundraising process that acted as catalysts for successfully closing FOAK funding. Additionally, startup informants identified certain conditions more critical than others for optimal outcome. These were defined as 'catalyzing conditions'. These 'catalyzing conditions' are likely to explain the identified configurations of conditions and how they are connected to the outcome. The data analysis for this part was done in Excel where each condition and case were analyzed on following scales: I = strong support from interview, i = modest support from interviews, p = support from secondary data and * = identified necessary condition ('catalyzing condition') for the successful close of the FOAK financing package. Strong/modest support from interview indicated the intensity of the condition. Strong support from interview was seen if the informant brought up the topic without probing, they strongly agreed on the matter or they brought it up many times (frequence). The Excel file included explanations for why each case/condition belonged to certain category. For example, if a case/condition belonged to 'I*', it included quote/other justification that indicated this. This was used to make the writer justify each score, increasing the validity of the analysis. The results of this analysis step are shown in Table 8.

Developing configurations: To facilitate even further cross-case analysis, the cases were also analyzed against several other dimensions to look for within-group similarities coupled with intergroup differences. As explained by Eisenhardt (1989, p. 540), "dimensions can be suggested by the research problem or by existing literature, or the researcher can simply choose some dimensions." Following this idea, cases were for grouped based on different factors, such as startups' ability to mitigate main FOAK risks that emerged from the first qualitative study (such as market/customer risk and technology risk). Another key element in the derivation of configurations was looking at cases with similar catalyzing conditions. Through iterative process, the cases were grouped by different variables until consistent patterns and themes emerged from the data. It is important to note that all cases may incorporate elements from the identified configurations. For instance, both commercial validators and technology demonstrators may efficiently utilize customer validation. The emerged configurations are shown in Table 9.

List of conditions

Offtake agreements ('Offtakes')

The first qualitative study revealed that investors often see market and customer risk among the highest risks for FOAKs. To mitigate this risk, climate tech startups can sign offtake agreements even before the construction of the FOAK. The construct offtake explains whether the climate tech startup had signed offtake agreements before or during the fundraising process. The construct is measured as a three value scale, where:

● indicates presence of binding offtake agreement
◑ indicates presence of a non-binding agreement, such as a Letter of Intent
○ indicates no observed commitment between startup and potential offtaker

Amount of collateral ('Collateral')

FOAKs frequently encounter challenges in obtaining senior debt financing. Collateral can contribute positively to securing this capital. The construct collateral measures the collateral value of the FOAK plant. The first qualitative study revealed that the equipment often holds most of the collateral value in a FOAK plant. Note that the measure is based entirely on the author's interpretation of the data and does not incorporate any detailed valuations specific to the plant. The construct is measured as a three value scale, where:

● indicates large share of standard equipment (high collateral value)
◑ indicates moderate to low share of standard equipment

Grant funding from public sources ('Grant')

Construct measures whether the studied FOAK financing structure involved grant funding. The grant especially improves the return of the project. The construct is measured as a two value scale, where:

● indicates presence of grant funding
○ indicates absence of grant funding

Equity or junior debt financing from public sources ('Public junior debt/equity')

Construct measures whether the studied FOAK financing structure involved equity or junior debt financing from public sources. These two sources of financing where merged together due to the same source (public money) and their shared role as risk-tolerant forms of capital within the FOAK capital stack. Both instruments serve as a financial cushion that absorbs first losses, enhancing the attractiveness of the project to senior lenders. The construct is measured as a two value scale, where:

● indicates presence of public junior or equity financing from public sources
○ indicates absence of public junior or equity financing from public sources

Involvement of a corporation ('Strategic')

Construct measures whether the studied FOAK financing structure involved participation of a corporation, i.e., whether there is an element of strategic partnership. Corporate involvement can play a crucial role in launching the project and driving its initial progress. The construct is measured as a three value scale, where:

● indicates presence of a large investment from corporation, such as a joint venture
◑ indicates presence of a corporation as a minority equity investor
○ indicates absence of corporation

Senior loan from private sources ('Senior loan')

Construct measures whether the studied FOAK financing structure involved a senior loan instrument from private sources. The construct is measured as a two value scale, where:

● indicates the presence of a senior loan provided by a private financial institution, characterized by a risk-averse lending approach
○ indicates the absence of a senior loan provided by a private financial institution in the financing structure

Guarantee instrument ('Guarantee')

Construct measures whether the private senior loan instrument involved a guarantee instrument. Guarantees can play a critical role in senior loans by mitigating the lender's risk, which is often perceived as excessively high in FOAK projects from the perspective of a lender. The construct is measured as a two value scale, where:

● indicates a presence of a guarantee
○ indicates absence of a guarantee

Use of equipment leasing providers ('Equipment leasing')

Construct measures whether the studied FOAK utilized equipment leasing, which can affect the financing needs of the plant and, thus, the financing structure. FOAK startups can for example, fund some of the upfront project costs of the FOAK through equipment leases. The construct is measured as a two value scale, where:

● indicates use of equipment leasing
○ indicates absence of equipment leasing

Use of SPV structure ('SPV')

Construct measures whether the financing of the FOAK plant involved off-balance sheet financing (SPV, special purpose vehicle) or on-balance sheet financing. The construct is measured as a two value scale, where:

● indicates use of a SPV structure
○ indicates use of on-balance sheet financing

Renting or leasing the FOAK facility ('Facility leasing')

Construct measures whether the building of the FOAK plant was owned or rented/leased. For example, in greenfield FOAK projects, third-party investment in the property can unlock an equivalent amount of equity for the FOAK startup, affecting the financing of the FOAK plant by enhancing financial runway. The construct is measured as a two value scale, where:

● FOAK facility leasing/renting
○ FOAK facility owned by the startup

Table 7: I. COMPONENTS OF STUDIED FINANCING STRUCTURES

Overview of Financing Component Presence per Case

Case	**Offtakes**	**Collateral**	**Public grant**	**Public junior debt/equity**	**Strategic**	**Guarantee**	**Senior loan**	**Equipment leasing**	**SPV**	**Facility leasing**	**Outcome**
Vanguard	◑	●	●	●	◑	●	●	○	○	●	Fully funded
Pioneer	◑	●	●	●	◑	○	○	○	○	●	Fully funded
Wayfinder	◑	○	○	●	◑	○	○	○	○	●	Fully funded
Trendsetter	●	○	●	●	○	○	○	(●)	○	●	Fully funded
Trailblazer	●	●	●	○	○	●	●	●	○	(●)	Fully funded
Forerunner	○	●	●	●	○	●	●	○	○	●	Fully funded

●= *Condition present,* ○= *Condition not present, ()= Subject to change*

Key: the table illustrates the existence of financing conditions in each financing structure/case. See further definitions for the conditions in previous pages. The outcome means that the company has successfully closed funding for the plant, making it fully funded. If a condition has brackets, the informant gave a strong indication of the action, yet is was to uncertain to some degree.

Table 8: II. PATHS TO SUCCESSFULLY CLOSING FINANCING FOR A FOAK PLANT

Emerged Conditions from Interviews that Contribute to Successfully Closing FOAK Financing

Case	**Public grant**	**Public junior debt/equity**	**Offtakes**	**Capital stack**	**Guarantee**	**Facility leasing**	**Collateral**	**Contingent funding**	**Strategic**	**Equipment leasing**	**Contingency**
Vanguard	I*	p		I*	I*	p*	I*		i		
Pioneer	I*	i	I			p		I*	p		
Wayfinder		I*	i			I*		i	p		
Trendsetter	I*	I*	I*	i		p		i			I
Trailblazer	I		I*	p	I*	i	I	p		i	
Forerunner	I	I*		I	I*	i	i	i			

*I = strong support from interviews, i = modest support from interviews, p = support from secondary data, * = identified 'catalyzing condition' for close of the FOAK financing package. Guarantees were always categorized as catalyzing conditions due to their binary nature that facilitates senior loans.*

Key: the table illustrates the effects of the conditions to the outcome, i.e., successfully closing financing for the FOAK plant.

Table 9: III. EMERGED CONFIGURATIONS

Successful FOAK Archetypes

Emerged configuration	**Mutual element in configuration**	**Number of identified supporting conditions**	**Description of identified supporting conditions**
All cases (N=6)	Public funding; facility leasing		
Senior loan recipients (n=3)	Private senior loan including a guarantee	4	Collateral, public/(private) guarantee, existing capital stack, public support
Commercial validators (n=2)	Binding offtake agreements	3	Strong demand, team, customer validation
Technology demonstrators (n=2)	Demonstration of technology indicated as an instrumental element	4	Customer validation, techno-economic modeling, technology-specific factors, mature scaling stage

Key: the table illustrates the emerged configurations, i.e., subsets of cases that utilized similar strategies to successfully close funding for their FOAK plant. The number of cases in each subset may not sum to the total number of cases, since some cases might belong to several configurations.

4.2 Findings

All studied cases demonstrated favourable outcomes, as each startup had successfully closed its FOAK financing package. However, the paths to successful close of the FOAK financing package meaningfully differ, which makes for an interesting topic to study. The financing structures were studied to find mutual elements that were present in all of the cases (necessary conditions). These elements included public support and facility renting. Configurations that emerged from the case analysis were 'private senior loan recipients', 'commercial validators' and 'technology demonstrators'.

The first group, 'private senior loan recipients,' included startups that received senior loans from private sources. The first qualitative study revealed that there is often a scarcity of senior loans in FOAK financing structures. Some of the studied financing structures involved senior loans. This raised an intriguing question: what similarities exist among these cases? In other words, what makes a FOAK bankable?[6] The second group, 'commercial validators', emerged from two of the companies highlighting that binding offtake agreements and/or strong market-specific demand were the catalyzing conditions for closing the FOAK funding. Finally, the third group, 'technology demonstrators,' emerged from both the interviews with specific startups, which emphasized the importance of efforts to demonstrate novel technology, and the interviews with financiers that invested in the firms belonging to this group, which highlighted the need for a specific threshold of demonstration before committing to investment. The configurations that emerged from the case study are illustrated in Table 9.

4.2.1 Sufficient conditions

No sufficient conditions, i.e., conditions that are enough by themselves to successfully close the funding of the FOAK plant were found. The lack of sufficient conditions implies that FOAK financing structures require several types of financing, aligning with a concept of a diverse group of FOAK financiers that is discussed throughout the theoretical part of the study, such as Section 2.4.

The case studies validated the idea that a larger pool of capital providers de-risks the project. For example, a larger pool of financiers reduces the amount required from individual financier, and financiers may have varying levels of risk tolerance. One example that emerged was crowdfunding, where many retail investors contributed smaller amounts to fund a FOAK plant. The first qualitative study highlighted that one fundamental problem related to FOAKs is their risk-return ratio. Lack of sufficient conditions may imply that due to this risk-return ratio, FOAK financing calls for innovative financial structuring to efficiently de-risk these projects. The case interviews validated that commercial banks are risk-averse when it comes to FOAK financing. However, this aversion

[6] There are many conversations around 'bankable' FOAK project features, where bankable means that the FOAK project can access low-cost pools of capital such as bank debt. For more discussion on these matters, see Khatcherian (2022) and OCED (2024).

to risk did not prevent them from financing some of the studied FOAKs (discussed further in Section 4.2.3). These findings imply that risk-averse financiers can, indeed, participate in FOAK financing, yet their role needs to be carefully planned in terms of risks.

Some financing structures included 'patient capital' providers, who were able to catalyze further financing by committing to the project early-on. The capital needs of studied FOAK plants were such that no individual investors were able to cover them completely. Especially venture capitalists' small tickets were evident. Furthermore, public investors may have capacity to make larger investments, yet they might be constrained with the additionality of the funding, which was highlighted by the results of the first qualitative study. For example, public financiers may be able to bridge FOAK funding gaps, yet the mobilization of private capital still remains the main objective, public financiers may limit their funding to be only a certain percentage of the plant's investment cost or they might make contingent financing decisions that depend on the FOAK project's capability to attract additional private capital. In the context of additionality, public support is not a sufficient condition, as public institutions cannot act as 'gatekeepers', deciding which projects succeed or fail.

4.2.2 Necessary conditions

Two necessary conditions, i.e., conditions that must be present in order to successfully close the funding of the FOAK plant were found. These were public support (both non-repayable and repayable) and renting of the FOAK facility. The first one, public support, can be seen as a way to address the risk-return ratio in FOAK projects, which is often seen insufficient from the private capital providers' point of view. Facility renting, on the other hand, demonstrates the startups' capability to optimize their asset-heaviness, aiding in financial runway. Facility renting implies that the examined startups have identified capital intensity as a challenge in climate infrastructure and addressed it accordingly. Capital intensity was discussed in Section 2.3.2.

Public support

Public funding was found to be a necessary condition for private investment in all cases, yet not sufficient on its own to make the FOAK fully funded. All the financing structures had a public component. In addition, the private venture capital investors who participated in some of the rounds may also access public funds through governmental investments, which means the actual share of public funding in a specific financing package may be higher than the sum of public financiers' investments in the financing package.[7] All the startups agreed that the public component was an important element in the financing package. These results imply that financing structures must involve some type of element that improves the risk-return profile of FOAKs for private financiers. Public support

[7] For example, the yearly share of public funds in Finnish VC fundraising has varied between 11-30 percent in 2021-2023 (Finnish Venture Capital Association, 2021, 2022, 2023).

came in many forms, such as grants, debt with favorable lending terms, high-risk equity investments or guarantees. Another form of public support was facility-based backing, where a public entity rented or even built a FOAK facility for the startup. One company had a brownfield facility, which was partly renovated by a public entity for the FOAK use. Size of the public support also mattered. For example, the size of grants played a role, with some startups receiving grants that constituted a substantial share of the total investment cost of the plant. Some startups viewed especially the public funding component as the catalyzing condition for attracting other forms of capital in the financing package. One startup, in particular, saw a sizeable grant as a catalyzing condition for the remaining funding:

> *"It was precisely this public funding instrument — we received a public grant. Honestly, without it, we probably wouldn't have been able to gather the funding for the facility at this stage. Actually, our initial plans were even a little later than what we thought was realistic for raising the funds, but this significantly accelerated the timeline and made it possible. It also attracted both existing and new investors, given the opportunity provided by such substantial support. [...] So yes, it completely enabled the funding round."*

Another startup talked about the importance of public funding in their financing package, and saw two different forms of public financing – grant and subordinated debt – most critical elements in the fundraising process:

> *"[Public subordinated debt instrument and grant instrument] were the most critical elements. If we had missed the first one, we would never have gotten this off the ground."*

All cases, except one, received grant funding. The absence of grant funding was not due to a lack of effort. The startup that did not receive grant funding, Wayfinder, described the fundraising process:

> *"There was no [public support] to be found. [...] One public financier saw that our R&D [which they had previously received a loan] was still in progress and their textbook says that the R&D projects must be completed first and then re-investments come into consideration. [...] We also didn't get any money from [another public financier] because they don't take technology risk. [...] There are several financing opportunities in EU, but EU regulation is always based on existing regulation, and when you develop new technology there is no regulation for it yet."*

These findings highlight how novel technologies are sometimes negatively affected by the scarcity of existing frameworks or regulation, or how current regulation may be not designed to address the challenges that novel technologies face. One startup was affected by the fact that, even though it intended to use only renewable feedstock, the possibility of using fossil feedstock made the project ineligible for certain EU funding.

Facility renting

All startups utilized facility renting. For specifically two startups, Vanguard and Wayfinder, this renting structure was seen as a catalyzing condition. A contributing factor in regard to facility renting is whether the FOAK will be deployed as a greenfield or brownfield project. In greenfield projects, the FOAK plant is built to undeveloped land, whereas brownfield projects involve land that has been previously developed. This means that greenfield FOAKs have newly constructed facilities, while brownfield FOAKs can use existing facilities that are modified for the FOAK use. Greenfield projects often cost more than brownfield projects, which means that a third-party investment in the property within greenfield FOAK projects can unlock an equivalent amount of equity for the FOAK startup, enhancing financial runway. One startup identified third-party investment into the facility instrumental in the fundraising process:

> *"I really need to express may gratitude for [third party that financed the building of the FOAK]. They said they couldn't finance product development, but since this area is growing, they agreed to construct the building and have us lease it. And that was the deal."*

Another startup highlighted the capital-efficient aspect of selecting a brownfield location compared to a greenfield location:

> *"We are currently negotiating for a brownfield location, which is far more capital-efficient [compared to greenfield project] if it's feasible. Not all processes can be adapted to a brownfield site if the requirements can't be met in those facilities. But fortunately for us, our process is simple enough that it doesn't require building from scratch."*

Finally, the market aspect was also mentioned. One startup noticed a significant increase in brownfield sites as the market shifted during the FOAK planning process:

> *"Our perspective changed in regard [choosing between brownfield and greenfield location]. In the beginning, we conducted a study on brownfield locations and there was not a single brownfield location available that would have fitted our specifications. [...] Now, there are several suitable brownfield locations available to us. This shift is entirely due to the economic cycle."*

4.2.3 Senior loan recipients

Collateral values may increase the likelihood of receiving a bank loan. Even if a FOAK plant scales a novel technology, it may not require entirely non-standard equipment – large share of its equipment could remain relatively standard. All the senior loan recipients had relatively standard equipment, indicating higher collateral values. One senior loan recipient reflected on the topic:

> *"Even though our technology is patented, the process is mostly based on existing components. [...] The components are quite well available."*

However, when other startups were analyzed based on the standardness of the equipment, some startups that had standard equipment were not able to obtain senior loans. Therefore, the standardness of equipment is not a sufficient condition on its own for securing a senior loan. In some cases, despite the equipment being relatively standard, startups observed that lenders often assessed its value based solely on the raw material worth. One startup with relatively standard equipment reflected on reasons behind this:

> *"There is a risk that the equipment does not work how we have planned it to work. Then you need to modify them or transfer them to some other geographical location, which can cost a lot... This is probably what the [lenders] are thinking in their own risk-assessment."*

Equipment often holds greater collateral values compared to the plant's 'walls'. This argument was further validated by the observation that all of the startups rented their facilities. Another observation related to senior loan recipients was that loans were always accompanied by a guarantee, indicating that while a guarantee was a necessary condition for obtaining the loan, it was not sufficient on its own, as additional factors were also required to secure lender commitment. Nearly all senior loans included a public guarantee, highlighting the importance of public support. Lenders may see it difficult to finance FOAKs without guarantees. For example, Vanguard saw guarantee instrumental for securing a lender commitment. When Vanguard's lender was interviewed on their lending decision, they also highlighted the importance of the guarantee:

> *"Without such a guarantee arrangement, the bank risk would have been completely uncontrollable and impossible to implement."*

In terms of other conditions that increased startup eligibility for senior loans, public support and capital stack were mentioned. One senior loan recipient highlighted that since they operate in an industry where it is hard to sign binding offtake agreements in the FOAK stage, the importance of public support increases. Another lender talked about the effect of public support, emphasizing its role as the foundation for all financing:

> *"Grants, soft funding, convertible loans, and all other such instruments that*

can be thought of as 'soft' or junior, coming from state actors, without them these projects won't take off, not anywhere."

The lender also identified the capital stack as an important element, continuing:

"Everything essentially accumulates to the fact that you need to have that foundation first. [...] Then we assess whether we can join the overall venture. [...] It also depends on the type of existing investors involved. [...] If there are reputable VC funds with a strong track record, it certainly facilitates our decision-making process."

The three FOAK financing structures that involved private senior loans imply that risk-averse financiers can, indeed, participate in FOAK financing, yet their role needs to be carefully planned in terms of risks. For example, one commercial bank designed a complex financing structure that was targeted at a strictly isolated tangible assets inside the FOAK. Further, one startup was probed about how the startup was able to secure a senior loan. The startup said:

"It was kind of surprising that the bank participated. I have not directly asked their reasoning, yet one needs to remember that there is collateral involved and maybe the [loan] is not as risky to them after all, as it has been structured in a way that the risk is tolerable from their side."

These findings, along with other analyses of banks' involvement in the examined structures, emphasize that bank financing for FOAK projects often requires highly structured arrangements to secure their participation:

"I do see that banks can play a sensible role in FOAK financing, yet not maybe in such a significant role as some players may hope. [...] For [studied senior loan recipient], we utilized a highly structured, innovative structure with several components of public support. There needs to by many actors involved in FOAK financing structures, as they can take on different risks."

4.2.4 Commercial validators

Two startups, ’commercial validators’, defined binding offtake agreements as catalyzing conditions for the successful close of FOAK financing. Trendsetter pointed out a significant demand from the customer’s customer. For this startup, robust demand fostered an environment that facilitated the signing of offtake agreements. Moreover, the startup had created a product that not only answered to tightening regulations but also improved the product characteristics at a competing price point. The startup saw customer-first approach as one key element for success: instead of developing the technology without prioritizing its practical applications, the startup first saw the problem the customers were facing, and then started to develop the technology to address it:

> *"We know exactly what the customer wants. [...] We understand the competitors too. [...] In our industry, agreements like this usually aren’t made. [...] But we’ve been making agreements for up to two years in advance, which should not be possible. This is mainly because the demand is so enormous for our customer’s customers. [...] [Our customers] know they’ll be able to sell it and probably get a better price than what they currently get for existing products.”*

Trailblazer was also able to sign binding offtake agreeements. When asked about the most important factors that contributed to the close of FOAK funding, the startup identified offtake agreements as an instrumental factor:

> *"[Offtake agreements] have essentially been the critical factor. Especially in the current less favourable financing environment, it usually requires a two-way approach. That is, it concerns both the incoming raw materials and the sales of the outgoing products. [...] One of the most important things has been the contractual commitment for both the incoming material and the outgoing material. This has been the critical pivot point for us, enabling the arrangement of various financing options."*

The findings emphasize the importance of a skilled commercialization team. A strong understanding of the industry, including customers and competitors, can provide valuable insights into the needs of potential buyers. Additionally, experience from cross-industry commercialization efforts can further strengthen a team’s ability to succeed. Finally, startups highlighted the importance of customer validation:

> *"Many [customers] also want to conduct some kind of test run on their own final product production lines before committing."*

Customers may be more willing to sign binding offtake agreements after testing the product. Commercial validators had effectively produced test batches in their demonstration plants that were sent to customers:

> *"Typically, almost everyone first builds some kind of demo or a smaller-scale*

> *facility to demonstrate the technology and its customers. This was also the case for us. We quickly built a demo after the launch of our company, which allowed us to carry out customer validation. Customer validation has definitely been the most important factor for us in securing FOAK financing."*

When test batches are sent to potential offtakers before the construction of the FOAK, offtakers may be more inclined to sign agreements as they have a better understanding of how the products integrate into their own processes. The results revealed that customer validation does not necessarily require a commercially scale plant, as it can be successfully achieved using sub-scale facilities.

4.2.5 Technology demonstrators

Some of technology demonstrators' financiers required a certain level of technological demonstration before commitment. The first qualitative study highlighted that financiers vary in terms of their technology aversion, which is not only seen when comparing financiers in the public-private axis, but also when comparing financiers inside specific groups. This heterogeneity allows startups that effectively de-risk their technologies to access larger capital pools by appealing to a broader range of prospective financiers. One financier of a technology demonstrator described their investment criteria:

> *"But fundamentally, we need to see that there is an existing process in place. Products have been made, and they have been sold to customers. That the process has the elements to essentially to scale it up to an industrial level."*

How can technology be demonstrated prior to a FOAK, considering that technology demonstration is one core aspect in FOAK projects? Technology demonstrators illustrated several paths to technological de-risking. Many startups recognized the value of smaller-scale plants in demonstrating technology to potential financiers and customers. The technological demonstration that was established in these smaller-scale plants also relates to the customer validation. As described before, Trailblazer saw their demonstration plant instrumental in establishing customer validation and, in turn, signing offtake agreements. One technology demonstrator described:

> *"Our process has been tested and developed as well as to some degree proven in our pilot factory. It has certainly brought concreteness and also credibility as we have been able to show physical products that have been made in the pilot factory."*

One startup deployed a previously proven technology that had undergone specific modifications, yet the project still qualified as a FOAK. The startup noted that having the technology proven to a certain extent made it easier to present a compelling investment case for prospective investors:

> *"Yes, absolutely, we've definitely noticed during this funding round and in previous ones that it specifically reduces the technology risk in the eyes of investors and, of course, ourselves as well."*

Furthermore, other technology-specific factors allowed some startups to de-risk their technology. Although all the startups can be classified as deep-tech ventures, some had more complex processes compared to others. One of the technology demonstrators characterized their technology as less complex:

> *"We have tested our technology in our pilot factory, which has given credibility to our business case. [...] Yes, the technology is patented, yet I would not say our technology has the type of 'breakthrough novelty' as [gives an example of another deeptech startup]."*

Thorough techno-economical modeling can also support the fundraising process. Pioneer talked about the importance of techno-economic modeling:

> *"We've placed a strong focus on continuously modeling the techno-economics. It feels like sometimes startups might rush into things without necessarily having a very solid understanding of the techno-economics. We, on the other hand, have done very thorough techno-economic modeling."*

Finally, the findings show that the commercialization stage impacts technological risks. Startups with longer operational periods have more robust data to prove their process's effectiveness. Although most of the studied plants were at similar commercialization stages, there were some differences in the adoption readiness of their technologies.

4.2.6 Supporting conditions

While these conditions may not independently drive successful FOAK financing structures, they serve as complementing elements that may offer the needed support to close the funding for the plant.

Indication of commercial viability

Most startups had non-binding LOIs. While LOIs do not commit either party to a final agreement, they can indicate some level commercial traction that is expected from financiers. One financier said:

> *"None of our cases has ever been undertaken in such a way that there hasn't been any kind of signal from the market."*

As mentioned earlier, binding offtake agreements can efficiently de-risk FOAK projects, unlocking access to capital. However, one startup that did not have offtake agreements touched on issues related offtake agreements, and noted that even if they had initially thought to aim for binding offtake agreements, it's not that straightforward:

> *"Schedule-related clauses can complicate things. [...] We don't know what the energy prices will be, which greatly affects our production costs. And then there's the general question of what the price points other ingredients used in production will be when production actually begins."*

Another aspect related to offtake agreements was the effect of market conditions. This idea of market timing was introduced in an interview with a FOAK financier, who implied that the importance of offtake agreements had increased as time has went on, which was then reflected on the conditions of their financing. Furthermore, Trailblazer discussed the market timing aspect:

> *"There's an element of market timing here. [...] In 2021-2022, there was a lot of capital circulating in the capital markets, so even smaller indications of commercial activity were sufficient. But as the amount of available capital has decreased, the criteria has tightened."*

One startup, Forerunner, did not have any binding or non-binding agreements in place. One reason could be that the company operated in a more specialized industry, with products that were more differentiated. Differentiation can work as an alternative de-risking strategy if offtake agreements are not available (OCED, 2024), and differentiation can increase the project's upside potential from the perspective of certain investors (van den Heuvel & Popp, 2022). Forerunner talked about offtake agreements in the context of their business, and concluded that their business model does not fit as well with pre-purchase commitments for large quantities:

"Generally, [offtake agreements] are really good at this point of the commercialization. [...] I think they do not really fit into our business as well as to some other type of business, such as more bulk production."

Capital stack

Findings suggest that several components of the financing package can be dependent on each other or trigger the commitment of other type of capital. Vanguard executed fundraising on three fronts, where commitment from equity investor triggered lender commitment:

"In the end, the solution came about in such a way that the loan instrument had progressed quite far, the grant was secured, and equity financing was under negotiation. So, things were moving forward on three different fronts. And what ultimately triggered it was that an equity investor came on board and made an investment decision, which then got the lender to move."

When probed about the importance of public support, Vanguard continued:

"Unfortunately, these projects don't always meet the [private capital] requirements. And that's where the public component is needed."

The startup also reflected that the guarantee instruments were instrumental in securing a bank loan. An interview with the lender further revealed that existing capital stack and public support were essential:

"Everything sort of cumulates on the fact that you need to have a solid capital stack there first. [...] Public support is also essential."

One of the startups was nearing the final stages of the financing process for its FOAK, with smaller portion of the required funding still uncommitted. Ultimately, it secured an investor. Reflecting on this experience, startup said:

"Everything else had to be ready first before the equity came through in the end. [...] The purpose of the press release was to attract the remaining equity investors, and it succeeded."

The findings from the interview with the previous startups' equity investor further validated the importance of the capital stack. When asked if existing capital stack can facilitate further funding, the investor answered:

"Absolutely. And especially since we're an early-stage investor, if we were to get involved in a later-stage case and there wasn't any kind of financing syndicate in place, it would be very easy to say, 'Okay, this isn't for us; it's too late-stage.' But on the other hand, if it's a situation where there's a small missing piece, and we see that our fund's return targets could be achieved with that case, then why not?"

Strategic partners

One factor that affects financing structures is the participation of corporations as strategic partners. Within different FOAK scaling mechanisms, joint ventures play an important part. Licensing can often be a preferred scaling mechanism from the perspective of the startup, yet incumbents may not want to take the technology risk of an unproven technology, suggesting that the licensing path is not truly open until the startup has built a FOAK. Illustration of FOAK scaling mechanisms based on the interview findings is presented in Figure 9.

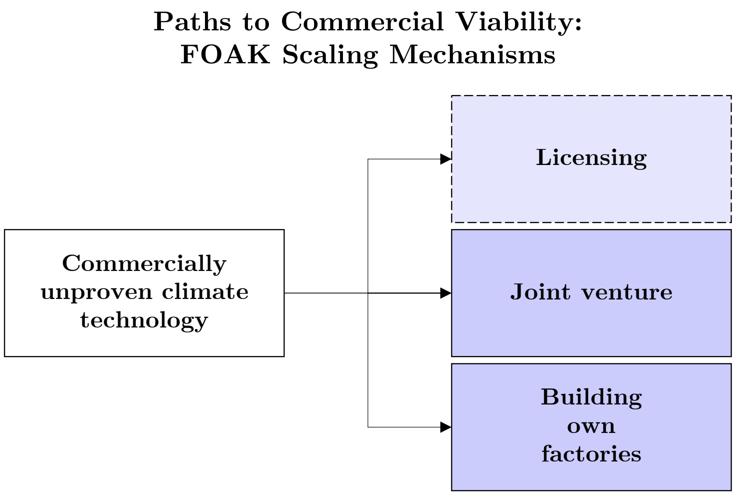


Figure 9: FOAK scaling mechanisms

The case findings highlight that involvement of strategic investors can be a very relevant element in FOAK financing. One startup's FOAK involved an investment from a strategic investor. This startup pointed out that choosing the scaling step of the FOAK a difficult question:

> *"If you build something small, it's easier to finance because there's less money involved. But on the other hand, if you start working with strategic investors, the more important factor becomes that if you build too small of a facility, it doesn't actually serve its purpose — it's not a FOAK, because it hasn't been scaled up enough."*

Another startup had initially thought about making the first commercial plant as a joint venture, but finally concluded on doing it by themselves in order to speed up the process:

> *"Our technology could be integrated into the other factory. [...] Practically speaking, the reason why we ended up [doing the plant by ourselves] is that things move incredibly slowly with these large corporations. We've been collaborating with a few for many years, and that continues, with the aim of eventually having such a facility. But at some point, we just had to take matters into our own*

hands to get the decision and also secure the cash flow."

None of the studied startups used joint ventures to build their FOAKs. One of the startups discussed the possibility of a joint venture, and saw it possible in the future, but not at current stage. The startup concluded:

"The good thing about joint ventures is that if it's truly something additive, where both parties benefit, then it can be a very sensible model."

Contingent funding

Several public financiers utilized contingent funding, i.e., their commitments were conditional to securing additional (private) funding. Public entity that financed one of the startups talked about the motivations behind such contingent funding:

"It stems partly from legislation, imposing restrictions that there must be private capital involved. [...] One of the best, if not the best, validations of the business potential of [FOAK] projects is securing funding from private professional investors. [...] There is a constant balancing act between driving speed, promoting and striving for societal impacts, and proceeding in a market-conformity manner."

For some of the cases, contingent funding decisions were able to trigger further investment, providing evidence that public institutions were successful in mobilizing private capital. For one startup, Pioneer, contingent funding decision acted as a catalyzing element for the successful close of the FOAK financing package. Company informant described the process:

"Of course, it attracted both the investors already involved in the company and the new investors, the possibility that with such significant grant – as long as the equity financing could be secured – which was the condition. So, [contingent grant] fully enabled the funding round."

Equipment leasing

Equipment leasing was seen as a supporting condition, yet most of the studied startups did not use it. One reason behind this was that some of the FOAKs used non-standard equipment, which limited the availability of appropriate leasing options. Trendsetter talked about equipment leasing, highlighting problems with the availability of different leasing options, especially in the FOAK context:

> *"Yes, we could use a leasing model on our part, but the availability of such options has been really poor. [...] That's probably because there's no track record since something like this has never been done before. [...] Maybe the other factor is that you can't just get this kind of equipment off the shelf. [...] Now that we've managed to put together a financing package of some kind, we're going to start revisiting the leasing option."*

Trailblazer, on the other hand, had already decided on using equipment leasing. Trailblazer's leasing decisions were enabled by a large pool of standard equipment. However, the startup noted that equipment leasing can often be very expensive from the startup's point of view:

> *"We do plan to use leasing for some of the equipment we use. [...] Yes, leasing is definitely a sensible element, but it's something where its share of the overall project cannot be very large because it's really expensive."*

Pioneer also saw leasing as possible avenue, yet it was only suitable for some parts of the process:

> *"We've discussed it with the leasing providers, and let's say it's still possible that something like that could come about in the future. [...] This would concern specifically the larger main equipment that would be suitable for leasing companies to offer leasing for."*

Finally, one startup touched on the inefficacy of equipment leasing in the context of their FOAK plant, noting that it was not beneficial because the most valuable component of the investment concerns non-standard equipment:

> *"In principle you could lease parts of the equipment, but we did not. The most valuable part of the investment are the components which are largely specific to our own use. I talked with one financier and they also told in our case there is no need for leasing arrangements."*

De-risking plant construction: EPC(M) and contingencies

The first qualitative study revealed that financiers have experienced cost overruns in FOAK projects. These overruns have partly been due to unexpected external shocks. Contingency reserves can cover unexpected costs that may arise from the plant construction. One case firm in particular, Trendsetter, saw contingency reserves as a way to increase FOAK investment readiness:

> *"[Financial buffers] have likely been a critical factor influencing the [successful close of the FOAK financing package], as we've had rather large contingency reserves and allowances for additional work compared to other startups. And yet, the model still holds up, which is something [financiers] wanted to see."*

EPC(M) contracts with engineering firms that manage the project and agree on the price upfront can also de-risk plant construction. For instance, one financier suggested that if an EPC(M) provider is already in place and the cost of the construction project is agreed upon in advance with the factory delivered as a turnkey solution, it can reduce uncertainty related to the construction project.

Final notes: Considerations on off-balance sheet financing

None of the startups utilized off-balance sheet financing. Therefore, use of SPVs was not identified as a contributing factor to the successful close of FOAK financing in the context of this study. When asked about the topic, some startups considered off-balance sheet financing for future plants. The lack of firms that utilized SPV-structures can be explained by at least two factors. First, study lacked participation of FOAKs that were established with a joint venture model. Second, the commercialization stage affects the financing models. For example, OCED (2024) study 21 demonstration and deployment FOAK projects and find that for early demonstrations, project-level financing is rare. Similarly, the studied FOAK plants may be too early in their commercialization stage to utilize project-level financing. The definition of a FOAK differs from source to source, with some definitions[8] excluding demonstration projects as FOAKs and other definitions[9] including them. In this study, demonstration projects that are large enough to demonstrate the commercial viability of the project are considered as FOAKs. This variation between FOAKs in different stages of commercialization – ranging from large pilots, early demonstrations, late demonstrations to early deployments – can effect the chosen financing models.

[8] See Khatcherian (2022, p. 12)
[9] See OCED (2024, p. 9)

Table 10: Emerged catalyzing strategies (1/2)

Challenge and solution	**Quote**
Customer/market risk Offtake risk agreement	*[Talking about how the company has successfully closed the financing and attracted investors]: That's likely because we've been customer-oriented from the start. We've had customers from the get-go, we've had purchase agreements, and we know exactly what the customer wants.*
Customer/market risk Offtake risk agreement	*Yes, customer validation [in the form of offtake agreements] has absolutely been the most important factor for us in arranging the FOAK funding.*
Scarcity of private capital Public support	*Unfortunately, these projects don't always meet the [private capital] requirements. And that's where the public component is needed.*
Scarcity of private capital Public support (soft or junior)	*Yes, these: grants, soft funding, convertible loans, and all other such instruments that can be thought of as 'soft' or junior, coming from state actors, without them these projects won't take off, not anywhere.*
Scarcity of private capital Public support (guarantee)	*Without such a guarantee arrangement, the bank risk would have been completely uncontrollable and impossible to implement.*
Scarcity of capital Facility renting	*I really need to express may gratitude for [third party that financed the building of the FOAK]. They said they couldn't finance product development, but since this area is growing, they agreed to construct the building and have us lease it. And that was the deal.*
Scarcity of capital Public support (soft or junior)	*It was precisely this public funding instrument — we received a public grant. Honestly, without it, we probably wouldn't have been able to gather the funding for the facility at this stage. Actually, our initial plans were even a little later than what we thought was realistic for raising the funds, but this significantly accelerated the timeline and made it possible. Of course, it also attracted both the investors already involved in the company and new investors, given the opportunity provided by such substantial support. [...] So yes, it completely enabled the funding round.*
Scarcity of senior debt Maximizing collateral	*It needs to be isolated, and by isolated I mean that instead of financing, for example, a factory, you could finance something specific. [...] You could create a working capital financing solution. [...] That's where the collateral value comes into play — the walls themselves have very little collateral value.*

Table 11: Emerged catalyzing strategies (2/2)

Challenge and solution	**Quote**
Scarcity of senior lenders Maximizing collateral	*It depends a bit on the situation, but usually, the technical production line is the most valuable part if we think about what it costs. It's not really the walls.*
Scarcity of private capital Public funding (soft or junior)	*[Public subordinated debt instrument and public grant] were the most critical elements. If we had missed the first one, we would never have gotten this off the ground.*
Scarcity of private capital Contingent financing decisions	*With the grant, we had to secure a certain portion of our equity by the timeline, or they would have withdrawn the application. So we had to make sure it was in place by that point. [...] [Both public funding instruments] were conditional the whole time. [...] Everything else had to be ready first before the equity came through in the end.*
Scarcity of private capital Contingent financing decisions	*[Junior public funding] also played a role in enabling us to gather the entire remaining portion of funding that was required as a condition for the grant funding.*
Scarcity of private capital Existing capital stack	*The purpose of the press release was to attract the remaining equity investors, and it succeeded.*
Scarcity of private capital Existing capital stack	*Talking about funding often has a positive impact, as we've seen before.*
Scarcity of private capital Equipment leasing	*Yes, we do plan to use leasing. [...] However, its share in the overall project cannot be very large because it is extremely expensive. [...] The more common the equipment, the easier it is to arrange leasing for it. [...] Most of our equipment consists of standard devices, and significantly smaller portion of them is highly specialized. This means we have quite a large pool of equipment that we could lease out.*
Scarcity of senior debt Existing capital stack	*It's been a result of many factors coming together. [...] And it's been a process where the project has been advanced over time. And in the end, the loan instrument had progressed quite far, the grant was secured, and equity financing was under negotiation. So, things were moving forward on three different fronts. And what ultimately triggered it was that an equity investor came on board and made an investment decision, which then got the lender to move. That's how it was ultimately resolved.*

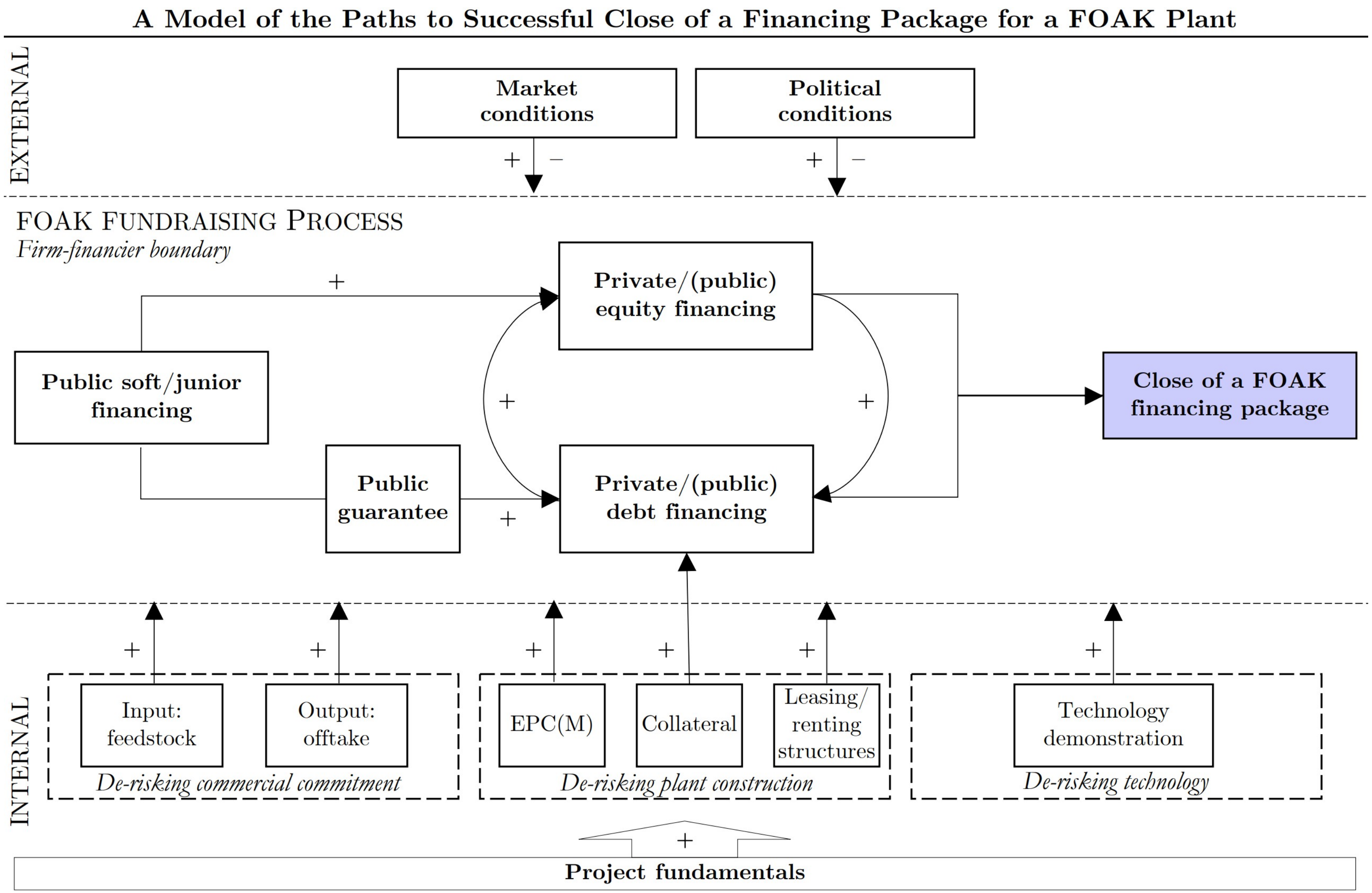


Figure 10: Proposed model

5 Discussion

This section synthesizes the findings from previous sections into a proposed model for FOAK financing. It also discusses the study's contributions to literature, limitations of the study and discovers potential avenues for future research.

5.1 A simple model of FOAK financing

The proposed model identifies paths to successful close of the FOAK financing package and factors that affect it. The model is shown in Figure 10.

I. Internal environment: FOAK startup

Market and technology risk were identified as the largest FOAK risks, suggesting that if a startup is able to effectively de-risk these elements, it can increase likelihood for attracting capital. This was demonstrated in the case study, where two FOAK archetypes emerged: technical demonstrators and commercial validators. In the model, the mechanisms by which startups can increase the investment readiness of the FOAK are divided to three categories: de-risking commercial commitment, technology and plant construction. One of the biggest market risk mitigants were offtake agreements. Several financiers identified them important while considering a potential investment. Obtaining offtake agreements in FOAK projects can depend on sector-specific demand and the technological maturity. Skilled commercialization professionals can aid in securing offtake agreements. Product differentiation can work as an alternative de-risking strategy if offtake agreements are not available. De-risking commercial commitment also comes in terms of input, i.e., securing feedstock agreements. Due to differences between FOAK projects, some feedstock-dependent projects may face higher risks regarding feedstock availability, cost and quality. Technology can be de-risked in various ways. The number of operational hours reflects technological maturity, with longer tests offering more performance data. Testing in smaller plants before the FOAK stage can demonstrate the technology's viability for commercial use. These plants allow customer validation. Needed technological de-risking efforts can depend on TRLs that vary both between and within ventures. One case featured a patented process within a first-of-a-kind commercial-scale plant, but the overall technological risk was lower compared to others due to the simpler process. Another case involved a process that partially utilized technology at TRL 9, while other parts of the process were at much lower TRL. Many informants also highlighted financial risks, such as large cost overruns. Using an established EPC(M) partner in the construction phase with an agreement on the cost and a turnkey delivery model can de-risk the construction phase. Standardized equipment can help startups both maximize their collateral (attracting lenders) and unlock access to equipment lease financing. Third-party investment in property, especially in greenfield projects, can unlock an equivalent amount of equity for the startup, enhancing financial runway.

II. Firm-financier boundary: FOAK fundraising process

Public funding was found to be a necessary condition for private investment in all cases, but not sufficient on its own to successful close of the FOAK financing package. Public grants can improve the likelihood of subsequent private financing (Howell, 2015; Islam et al., 2018). The case studies revealed a consistent pattern, with the initial step in the FOAK financing package typically being the commitment of public grants or junior debt, suggesting that public support improves the risk-return profile of the project, mobilizing private capital. Public instruments can have 'built-in' mechanisms for mobilization of private capital in the form of contingent financing decisions. The catalytic effect of financing extended beyond public commitment, as private commitments can also trigger each other. Resource inflow through signaling and resource effect provided by VCs can promote entrepreneurial firm performance (Liang et al., 2019), and startups backed by well-networked VC firms have a significantly larger probability in reaching later financing rounds (Hochberg et al., 2007). Case studies highlighted that the track record of existing investors can improve the credibility of the venture and, thereby, possibly facilitate further investment. Existing capital stack – regardless of track record – can also stimulate further investment. Interviews with FOAK financiers imply that the risk-taking capacity of private investors alone appears insufficient to scale technologies at the pace required to meet emission targets. The first qualitative study revealed that while several informants recognize an urgent need to scale climate technologies, not many private capital providers are willing to be the risk-taker, highlighted by FOAK funding gaps.[10] As most of the financing challenges center around the risk-return ratio of FOAK projects, one major implication is that the market simply needs more risk-taking investors. Due to private capital's unwillingness to bear the risk, almost all informants agreed on the importance of public support. However, public financiers balance with the additionality of their funding. It is important to think about the broad toolbox around different public instrumentation. The instrumentation must be carefully chosen based on the specific context and the intended impact (Olmos et al., 2012; Polzin et al., 2015). One perspective to keep in mind is how to achieve the maximum possible effect with the smallest possible intervention and which public instruments can mobilize the most private capital. For example, Polzin et al. (2016) argue for case-specificity through combination of different financial mechanisms. This can involve combining grants with private financing instruments when seen appropriate. Finally, it should be noted that it is not only public institutions that can take on more risk. Impact-first private investors can also play a crucial role in bridging the FOAK funding gap. The significance of these actors grows when governmental actions lack consistency.

[10] Specifically in Finland, yet findings highlight the universal FOAK 'valley of death'.

III. External environment: Outside factors that influence FOAKs

External environment affects the fundraising process. For example, Bell et al. (2012) find that a venture's IPO can be affected by signals from the institutional environment. Market conditions can influence the financing structures of FOAKs by impacting the availability of capital. For instance, one startup ultimately adopted a more diversified financing structure than initially planned due to a shift in market conditions. In recent years, crowdfunding has become more popular for clean tech companies, offering financing for innovative small businesses and helping early-stage clean tech firms grow (O'Reilly et al., 2021). Crowdfunding was identified as a way to access capital in demanding market conditions. One aspect within political environment is the continuity of it. Cumming et al. (2016) argue that government should create long-term, stable and predictable policy, which facilitates demand for clean energy. Lacking consistency within innovation policy can lead to uncertainty and potential impeding of private sector investment (Uyarra et al., 2016). There are instances where policies that support FOAK financing have been initially implemented but discontinued at a later stage. These types of policies were also identified in the empirical section of this study. The informants highlighted that within policy uncertainty, it is harder to make reliable plans or attract investors to underdeveloped markets. An example of regulation that supports FOAK scaling is stricter regulation for the startup's direct customers or the customers customers. Especially one startup was positively affected by this: the startup successfully secured offtake agreements in an industry where such agreements are not typically a standard practice. Regulation can also have negative effects in the form of regulative barriers. For example, regulation related to food (e.g., alternative proteins) can be harder to obtain in the Europe than the United States. Moreover, regulation can unintentionally hinder innovation due to lack of financing frameworks for emerging technologies. This can slow the progress of new technologies, defeating the purpose of technology neutrality by prioritizing existing technologies over innovative ones.

5.2 Comparison and discussion of the results with previous studies

Existing body of research has studied the financing of climate technologies (Masini & Menichetti, 2013; Mazzucato & Semieniuk, 2018; Mukherjee et al., 2024; Owen et al., 2018, 2020; Polzin et al., 2016; Polzin, 2017; Polzin et al., 2019), among others, especially focusing on IVC perspective (Bürer & Wüstenhagen, 2009; Gaddy et al., 2017; Mrkajic et al., 2019; Nanda, 2020; Nanda & Ghosh, 2014; Nanda et al., 2015). This paper adds to existing research on financing climate innovation, but with a specific focus on FOAKs. As such, it is the first study focused specifically on FOAK financing, presenting new findings of interest to startups, financiers, policy makers and academia. Startups can use the results to increase the investment readiness of their FOAK projects, and utilize similar strategies as the startups who were able to successfully close funding for their FOAK plant. These strategies can come in different forms which, in turn, tackle different FOAK challenges, such as market (FOAK archetype 'commercial validators') and technology risk (FOAK archetype 'technological demonstrators'). Furthermore, several strategies can be utilized to make FOAKs bankable, i.e., eligible for senior lenders. From the financiers' point of view, the interview findings can provide an unique viewpoint to the perspectives of both the startups and fellow financiers across the capital stack. One implication for policymakers is that FOAK projects require a stable political environment in order to accelerate the path to commercial viability. The findings of the study are based on a relatively new area of investigation, which may lead to limitations in generalizability. Lack of literature on this topic means that certain identified dimensions – such as the non-generalizable nature of FOAK projects and variations in FOAK definitions, which influence studied scaling stages and related financing structures – may not yet be fully understood, and the study's conclusions should be interpreted with this in mind. Further research is needed to build upon these initial findings and refine the understanding of FOAK financing in different contexts. One of the main contributions of the the study is a simple model on FOAK financing (Section 5.1) as an attempt to contextualize the complex financing process of innovative, yet risky FOAK projects.

On the broader topic of financing climate innovation, the results of the study align with findings of existing body of research. The largest contribution is around the fundamental problem of risk-return ratio of FOAK projects, implying need for risk-taking investors to mobilize private investment. In the context of case studies, this was achieved through public instrumentation. Similar arguments for public support to overcome funding barriers have been made in the existing body of literature of climate financing (Cecere et al., 2020; Polzin et al., 2016; van den Heuvel & Popp, 2022). Authors have advocated for a collaborative approach involving different stakeholders in the context of climate tech financing (Dalla Fontana & Nanda, 2023; Gaddy et al., 2017; Nanda, 2020). Some argue that climate tech requires use of 'patient capital' (Dalla Fontana & Nanda, 2023; Owen et al., 2023), such as government grants and impact-first investments. Cowling and Liu (2023) point out the funding gap in patient capital in the context of climate tech financing and Owen et al. (2023) argue that access to long-term, patient capital continues to be a significant challenge. This paper provides evidence that the risk-taking capacity of private investors alone still appears inadequate to scale climate technologies at the pace needed to meet climate targets, highlighting the critical role of this type of patient capital. The six case studies highlight public institutions as patient capital providers, but it's important to recognize that private institutions can play this role just as effectively. The critical question remains on how to de-risk and mobilize private capital to close funding gaps. The thesis points out that financial structuring can, indeed, help facilitate involvement of private institutions which prioritize returns over impact. Ultimately, the success of climate financing depends on not who provides the capital, but on how effectively it is mobilized – or de-risked – to drive lasting impact.

5.3 Limitations of the study

Multiple-case study research design has limited generalizability. Since case studies focus on a smaller number of cases in greater depth, the findings may not be broadly applicable to other contexts. For example, case studies do not include companies whose FOAKs were developed through joint ventures. These types of FOAKs were identified and approached to participate in the study. However, none of them agreed on participation. As discussed in the study, strategic partnerships are an important scaling method and can affect FOAK financing structures.

During the study it was revealed that the definition of a FOAK varies. This can lead to people talking about different phenomenon. For example, one informant considered Northvolt Ett to be a FOAK, and another one did not. Northvolt Ett is not considered to be a FOAK in this study, since secondary data suggests that the technology is not novel enough to demonstrate first-of-a-kind application. This could also explain the large amount of capital the company has attracted, as it has less technology risk. However, Northvolt Ett does have FOAK elements and could in some other scope be defined as a FOAK due to it being the first of its size battery plant in Europe. To address the uncertainty surrounding the definition, the interviews typically began with a discussion around the definition of a FOAK plant.

The geographical focus of this study is the Nordic region, which may limit the generalizability of its conclusions to other regions, such as the United States. These differences stem from variations in investor dynamics and governmental interventions. For instance, the EU Green Deal and the Inflation Reduction Act have structural differences in their approaches to supporting green investments.

Some of the informants highlighted the shift in market conditions that was seen after 2021. Interest rates remained near zero before 2022, creating a favorable environment for accessing capital for infrastructure-related projects. However, increase in interest rates has significantly impacted access to capital, affecting FOAK projects. These conditions are reflected in the data, as the market had not fully recovered to its earlier state by the time of the interviews in late 2024.

The thesis' findings may have alternative theoretical explanations than those proposed. For example, senior loan recipients might have other underlying factors then those presented behind the ability to secure such loans. One alternative explanation could be that senior loan recipients may have better ability to cultivate and leverage commercial bank relationships compared to others. Sample size of the interviews could also be made larger. The informants' opinions are subjective and may not always capture all the nuances of multi-party transactions. The case study in this thesis puts most emphasis to the startup informants' view on the fundraising process, which may offer contrasting views to other participants of the transaction.

5.4 Avenues for future research

Novel topic offers many viable future avenues of research.

Scaling mechanisms: One factor that largely impacts the financing of the FOAK plants is the chosen scaling method. For example, if the startup decides to fund the FOAK with extensive support of a corporation, reliance on other financing sources decreases. As mentioned in Section 5.3, case studies did not include a FOAK plant which was done with a joint venture model. An interesting future avenue of research could be to analyze the different FOAK scaling choices and their outcomes, including joint ventures.

Public support: Public support for FOAKs was seen instrumental from both the perspective of startups and financiers. The topic raises questions on what form of public support is most efficient and why. Moreover, what type of public instrumentation mobilizes private capital the most? Grants are often seen as the best instrument from the both private investor (increases IRR) and startup (non-repayble funding) view. However, due to their non-repayable nature, grants are among one of the most expensive forms of support. Another consideration is the investment terms: should all creditors have the same priority in terms of repayment ('pari passu') or should for example public institutions take on more risk (e.g., junior loans). Carefully designed investment terms can help manage costs and facilitate private financing in FOAK projects. The additionality of the public support is also an important point: does the involvement of the public institution enable the execution of FOAK project in larger scale, faster or at all?

Mixed-methods study: The topic would suit a mixed-methods study. Sequential quantitative phase could test the statistical validity of proposed relationships. This dual-phase ensures a more holistic understanding of FOAK financing. Researchers often use a sequential approach in mixed methods studies to improve conclusions, allowing the use of results from one method (qualitative or quantitative) to guide the other method (Greene, 2007; Greene et al., 1989). A mixed-methods sequential exploratory design suits research contexts where existing theoretical frameworks fail to offer explanations for the relationships under investigation (Creswell & Plano Clark, 2007). As a novel topic, FOAK financing suits this setup. Levasseur et al. (2022) argue mixed methods to suit VC context especially well, as it helps address broader research questions, offer deeper and more complete understanding as well as conduct more process-oriented research related to entrepreneurship. The authors also point out how VC studies using only qualitative approaches could benefit from a complementing quantitative study.[11] At the time of the study, a larger quantitative study was ruled out due to lack of available data. Currently, there are no 'FOAK databases' or ways to identify FOAK deals. One approach for defining prospective data set could be: Start with a broader set of climate/clean technology startups. Filter for capex-intensive companies. These capex-intensive companies include both startups that own plants and startups that are equipment manufacturers. Exclude equipment manufacturers from the capex-intensive company dataset. Filter out companies that do not employ novel technology (first-of-a-kind). When you have the final FOAK startup list, you can search for the financing information of the plant in the desired/studied commercial stage.

Qualitative comparative analysis: Alternative research method that could aid in discovering conditions that contribute to the development of successful financing structures could be a fuzzy-set qualitative comparative analysis. This method builds on the idea that the conditions produce the outcome interactively, determining the necessary and sufficient conditions for an outcome by evaluating whether a condition or combination of conditions consistently appears within the subset of FOAK cases that exhibit the desired outcome. The approach could validate this study's results in a larger dataset.

[11] Bessière et al. (2020) conducted an exploratory case study involving equity crowdfunding, business angels and VCs. They found that as nascent ventures grew, VCs pushed for stricter governance structures. Levasseur et al. (2022) suggest that a follow-up quantitative study could test a hypothesis that, unlike the sequence of investments from business angels and venture capitalists, the sequence of crowdfunding investments (reward vs. non-reward) does not affect firm governance.

A Interview guide (Financier)

1. Background
   (a) Describe your current role and background in FOAK financing?
   (b) Describe your investment areas and stages?
   (c) What FOAK did you invest in and when?
   (d) How do you see the role of your organization in the investment ecosystem for climate technologies and, specifically, FOAK financing?
2. FOAK investment process
   (a) How do FOAK investments compare to more established projects?
   (b) What is your investment criteria in a FOAK project?
   (c) What kinds of financial instruments do you typically use in FOAK projects?
   (d) What are key indicators of commercial viability for a FOAK?
   (e) What are key commercialization blocks for a FOAK project?
   (f) How would you evaluate main FOAK risks from the perpective of an investor from 1...5 where 5 is most risky?
3. FOAK financing
   (a) Who are the investors that are currently engaged in FOAK projects?
   (b) What is the role of each investor? Why would you want to have a [specific FOAK investor] in the project?
      i. How important is having a diverse investor base, e.g., why would it be better to have a VC investor and a project financier instead of having all the money come from a VC?
   (c) What are the most common financial instruments that are used to finance a FOAK project and why?
   (d) How does a financing structure for a FOAK project look like in terms of the amount of:
      i. Equity
      ii. Debt
         A. Senior debt
         B. Subordinated debt
         C. Guarantees
      iii. Grants
      iv. Some other financial instrument?
   (e) What is the role of project finance and the use of SPVs – are most FOAKs financed with project financing?
   (f) How do you structure a FOAK investment case to ensure that all financing elements work together? [For example, walk me through one real-life example]

(g) What FOAK-specific strategies can be employed to build investment readiness or mitigate investment risk?
   i. Project-related strategies
   ii. Financial structuring strategies

(h) What are the typical terms in FOAK projects governing each financial instrument? (e.g., step-in rights if the FOAK project defaults on its debt)

(i) How do you see the role of public funding in FOAK financing? What about blended finance, i.e., catalytic capital from public or philanthropic sources?

4. FOAK financing challenges
   (a) What are the key challenges related to financing when investing in FOAK projects?
   (b) Is there currently a shortage of a certain financial instrument or investor type, and how does this affect financial structuring?
   (c) Have you personally witnessed the "missing middle", i.e., financing gap related to commercialization of FOAKs?
   (d) In your opinion, what are some tactics on how could the "missing middle" -problem be solved?

B Interview guide (Startup)

1. Background
   (a) Describe your current role and background?
2. FOAK financing process
   (a) Describe financing process in terms of how the final financing structure was determined? Why have certain type of capital over the other?
   (b) Did you encounter 'pivotal moments' that allowed successful close of the FOAK financing package? For instance, did securing certain type of financing act as a catalyst for another?
3. FOAK plant
   (a) What factors affect chosen scaling step, i.e., size of the commercial plant?
   (b) How has collateral values affected your decisions? Can you resell the equipment to other use, or is it highly specific to your own use? Did you use/consider equipment leasing?
   (c) What decisions have you made on the financing of the building?
   (d) What is your perspective on securing offtake agreements?
   (e) What is your opinion on utilizing strategic partnerships?
4. FOAK financing structure
   (a) Have you utilized off-balance sheet or on-balance sheet financing? What led you to decide to use one over the other? How do you structure the transaction so that different financing elements go together?
   (b) Under what terms has financing been obtained for the plant? Are there some specific conditions that investors are demanding in order to invest?
   (c) Have you encountered FOAK-specific strategies to build investment readiness or de-risk the investment? (e.g., offtake agreements/LOIs)
5. FOAK financing challenges
   (a) Have you encountered specific challenges related to FOAK financing?
   (b) Have you observed obstacles preventing certain investors from investing at all?

Declaration of AI use in the writing process

This thesis has utilized Artificial Intelligence (AI) in its research process. The AI use in this thesis aligns with Aalto University's Ethical AI Use Guidelines (Aalto University, 2025). AI-assisted technology was used to refine the thesis's language. AI tools were never given authorship and all outputs were carefully reviewed to ensure proper citation and factual accuracy.

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