Routledge
Taylor & Francis Group

Venture Capital

An International Journal of Entrepreneurial Finance

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tvec20

Financing green innovation startups: a systematic literature review on early-stage SME funding

Abhishek Mukherjee, Robyn Owen, Jonathan M. Scott & Fergus Lyon

To cite this article: Abhishek Mukherjee, Robyn Owen, Jonathan M. Scott & Fergus Lyon (03 Oct 2024): Financing green innovation startups: a systematic literature review on early-stage SME funding, Venture Capital, DOI: 10.1080/13691066.2024.2410730

To link to this article: https://doi.org/10.1080/13691066.2024.2410730

Published online: 03 Oct 2024.

VENTURE CAPITAL
https://doi.org/10.1080/13691066.2024.2410730

Routledge
Taylor & Francis Group

Financing green innovation startups: a systematic literature review on early-stage SME funding

Abhishek Mukherjee[a], Robyn Owen[b], Jonathan M. Scott[c] and Fergus Lyon[b]

[a]School of Accounting, Finance and Economics, University of Waikato, Tauranga, New Zealand; [b]CEEDR, Middlesex University, London, UK; [c]School of Management and Marketing, University of Waikato, Tauranga, New Zealand

ABSTRACT

This paper investigates the critical issue of financing early-stage green startups, examining the types of investors and finance models available, the challenges these startups face, and how the green finance ecosystem can better support early-stage investment. Utilizing a systematic literature review (SLR) methodology, we provide a comprehensive analysis of the current landscape. Our findings reveal a significant paucity of data and a bias towards well-established North American and European ecosystems, while highlighting an emerging diversity in private finance sources post-Global financial crisis (GFC), including grants, equity, and crowdfunding. Despite this, there remains a heavy reliance on public funding and a lack of evidence regarding its impact. The inherent characteristics of cleantech – high capital expenditure, long investment horizons, and disruptive nature – necessitate innovative public financing instruments and policies to reduce risk and attract private investment. Our theoretical contribution highlights the necessity for interdisciplinary research and policy collaboration to develop a holistic entrepreneurial finance (entfin) ecosystem. This approach should integrate quantitative economic and qualitative behavioural finance research to address information asymmetries and improve the green economy policy mix. Such a framework will support public-private co-financing, enhance stakeholder engagement, and provide evidence for policy decisions, facilitating more rapid commercialization of cleantech innovations for environmental sustainability.

ARTICLE HISTORY
Received 27 June 2024
Accepted 24 September 2024

KEYWORDS
Green innovation; SME; early-stage innovation; cleantech; policy; research agenda

1. Introduction

Given the academic and policy salience of green finance related to climate change and nature loss, this paper aims to offer a comprehensive account of prior work on early-stage green finance. Indeed, the final UN Intergovernmental Panel on Climate Change (IPCC, 2023) synthesis report emphasizes that investment in (green) technology represents a high priority pathway to environmental mitigation and adaptation. Further, Net Zero greenhouse gas (GHG) emission reduction targets by 2050 (Paris 2015) and land and water biodiversity

CONTACT Abhishek Mukherjee abhishek.mukherjee@waikato.ac.nz School of Accounting, Finance and Economics, University of Waikato, Tauranga, New Zealand

safeguarding targets at COP15 (2022) have also been established. Globally, the private and public investment gap finance was estimated to be over $100bn per annum (IPCC 2022, 2023). In reality, the investment shortfall is far greater, if climate and biodiversity are to be collectively addressed; and, as Owen, Brennan, and Lyon (2018) highlight, much funding has focused on large-scale infrastructure (e.g., for renewable energy, hydrogen production and storage and electric vehicles) which typically overlooks – and underinvests in – potentially game-changing green innovations developed by small and medium-sized enterprises (SMEs).

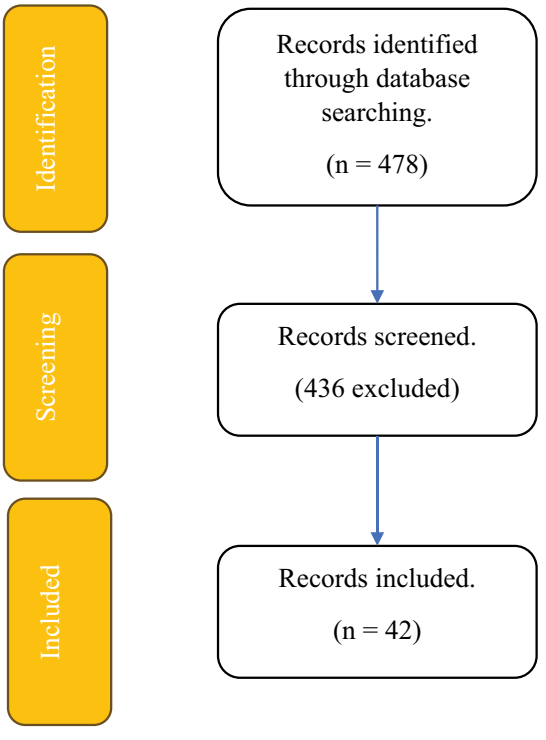
While the value of a systematic literature review (SLR) is acknowledged for setting out existing and future research on early stage business (Pantea and Tkacik 2024), there is a gap related to SLRs investigating the wide range of green innovation start up finance. Prior journal reviews are hampered by a narrow definition of cleantech which mainly focused on renewable energy and its related services (Gaddy et al. 2017) or having a predominance of papers focusing on European and North American green finance policies in mature economies (Owen, Brennan, and Lyon 2018). This paper spotlights the finance barriers facing early-stage green innovation SMEs and how these can be overcome by developing entrepreneurial finance ("entfin") ecosystems that combine finance provision with sustainability policy and practitioner actors.

It is particularly important to examine SME early-stage green innovation that includes innovation inception, proof of concept, research and development (R&D) prototyping and pre-revenue to early commercialization period (Mazzucato and Semieniuk 2018). This is known as the "valley of death" as it is notoriously high risk and difficult to fund, due to the high incidence of information asymmetries between entrepreneurs and financiers (Carpenter and Petersen 2002). Nanda (2020) highlights a persistent market failure for "deeptech", capital intensive, long horizon (often 10 years plus) investment in disruptive new technology. Investors do not comprehend such deeptech, since it requires multi-million investments to reach commercialization, and features a high risk of failure from technical, regulatory and market acceptance lacunae.

Arguably, this is exacerbated when green businesses combine commercial market and environmental good logics in their business models (Harrer and Owen 2022) and struggle to signal the value of their proposition to investors (Reuben and Fischer 2005). Both Owen et al. (2023) and Mazzucato and Semieniuk (2018) argue that this gap manifests into persistent SME green innovation market failures that require more strategic attention from state policymakers to establish green investment banking which meets the needs of SMEs as well as larger scale infrastructure projects, which have typically been their focus.

This research is particularly important in this current context with (1) the persistent under-funding of climate and biodiversity mitigation and adaptation; (2) growing recognition of how government intervention can co-fund and leverage more private investment for various green innovations (IPCC 2023); (3) recognition of the necessity for holistic entfin ecosystem approaches that address both the supply and demand for finance; and (4) the need for new forms of alternative finance to compensate for the contemporary lack of environmental valuation within the current capitalist economy (Polzin 2017).

In this paper, we therefore contribute to the practical and theoretical understanding of this vital part of green finance by exploring the following research questions: What are the types of investors and finance models for early-stage finance? What are the challenges faced by green early-stage innovation finance? And how can the green finance ecosystem support early-stage investment? The



Reason 1 = Published in predatory journals

Reason 2 = The article does not address the research question or topic of interest.

Reason 3 = Did not meet the quality threshold. (Publication from quality peer reviewed journals (e.g ABS 2* and above)).

Figure 1. PRISMA Flow Chart of SLR process.

paper is structured as follows. It commences with the method in Section 2. Then, the analysis in Section 3, the discussion in Section 4 and finally the conclusion in Section 5.

2. Method: review protocol

The parameters of the SME finance literature searched, the search strings applied, the bibliometric results and assessment undertaken is outlined below as per stages set out in Tranfield, Denyer, and Smart (2003). The process of the SLR is illustrated by Figure 1.

In Stage I (Planning), we identified the need for an SLR on early-stage green innovation finance to enhance understanding on early-stage green innovation finance of SMEs. Preparation involved drafting a scope of the review: an SLR of green innovation for SMEs to address a clear gap in the published literature on this topic and to provide a holistic overview of the research to date on this topic. Next, the review protocol was developed:

(1) Purpose: To synthesize recent research, thematic analysis and suggest future research.
(2) Research focus: early-stage green innovation SME finance.
(3) Source: Scopus database.
(4) Search String:

((“SME” OR “SMALL BUSINESS” OR “STARTUP” OR “SPINOUT” OR “SMALL AND MEDIU* ENTERPRISE” OR “INNOVATION” OR “SOCIAL ENTERPRISE” OR “ENTERPRISE” OR “ENTREPRENEUR*”) AND (“FINANC*” OR “INVEST*” OR “LENDING” OR “EQUITY” OR “VENTURE CAPITAL”) AND (“LOW CARBON” OR “GREEN” OR “CLIMATE” OR “SUSTAINABLE” OR “CLEANTECH” OR “ENVIRONMENT*” OR “SUSTAINAB*”)).

(5) Inclusion criteria

Research field Green innovation, Greentech, cleantech, climate tech.
Language: English.
Type of work: Academic peer reviewed journal articles.
Search Period: 2003 to 2023. This 20-year timeframe is chosen to cover literature following significant industry changes post-GFC (from the late 2000s), ensuring a comprehensive review of developments and shifts in cleantech finance, as highlighted in the literature (e.g., Gaddy et al. 2017).

(6) Exclusion criteria
- Publication from quality peer reviewed journals (e.g., ABS 2* and above).
- In this study, we ensured the exclusion of predatory journal publications by rigorously cross-referencing all selected journals with Cabell’s predatory reports.

Stage II (Conducting a review) involved conducting a thorough search on Scopus by applying the indicated search string and then refining by excluding results that were not salient to the purpose and research question of the SLR and not in 2,3 or 4* ABS ranked journals. Additionally we employed a snowball sampling process, reviewing references from initially identified high-quality sources. Any additional papers discovered through this method were subject to a consensus review by the author team.This process aligns with established techniques for conducting literature reviews in other domains, such as those outlined by Vanacker et al. (2022).

Data extraction involved an iterative process of coding of each paper by two co-authors using a systematic coding scheme developed building on initial literature reviews and with reference to highly cited existing papers. These were then transferred to NVIVO for analysis and thematic analysis using five codes: Code 1 (objective of study), Code 2 (financing challenges identified and discussed in the study), Code 3 (the role of the public sector discussed in the study), Code 4 (limitations of the studies), and Code 5 (further research opportunities identified in the studies). The top frequently occurring words for each code were identified and grouped into categories based on their themes. For Code 1, six themes emerged from the 65 most frequently used words, while Code 2 had eight themes from the 44 most frequently used words. Code 3 had four themes from the 37 most frequently used words, Code 4 had five themes from the 18 most frequently used words, and Code 5 had five themes from the 12 most frequently used words. Finally, Stage III (Reporting and dissemination) involves reporting the findings of

the SLR and getting evidence into practice), where we provide implications and recommendations for the practice of green innovation finance for SMEs.

3. Findings

The findings of this SLR of green innovation startup finance are presented in thematic order. These relate to investor types, financing challenges, financing models, support ecosystem and policy and underpin our aim for an integrated systems approach to understanding the green innovation entrepreneurial finance ("entfin") ecosystem.

3.1. Definition of green and clean technology sectors seeking finance

Figure 2 reveals that the research spans across many traditional and emerging sectors, including agricultural development (Andrieu et al. 2017), manufacturing (Awan, Arnold, and Gölgeci 2021; Gaddy et al. 2017; Ghisetti et al. 2017), clean energy technologies (Bento, Gianfrate, and Groppo 2019), and wider waste, material and environmentally positive technologies (Owen et al. 2023).

A discernible sector bias emerges towards clean energy technologies and agricultural development, reflecting the urgency and global emphasis on these areas for green innovation. An important contextual starting point discussed in the key literature is the definition of clean technology. Figure 3 offers a structured breakdown of the definitions adopted, demonstrating that the term "clean technology" has broader meaning than simply the production of renewable energy and related energy efficiency applications and services (Gaddy et al. 2017). Indeed, to some authors (Owen et al. 2023), it requires a broader "greentech" definition to encompass all aspects of environmental sustainability.

Figure 2. Sectoral focus. Source: developed from literature review.

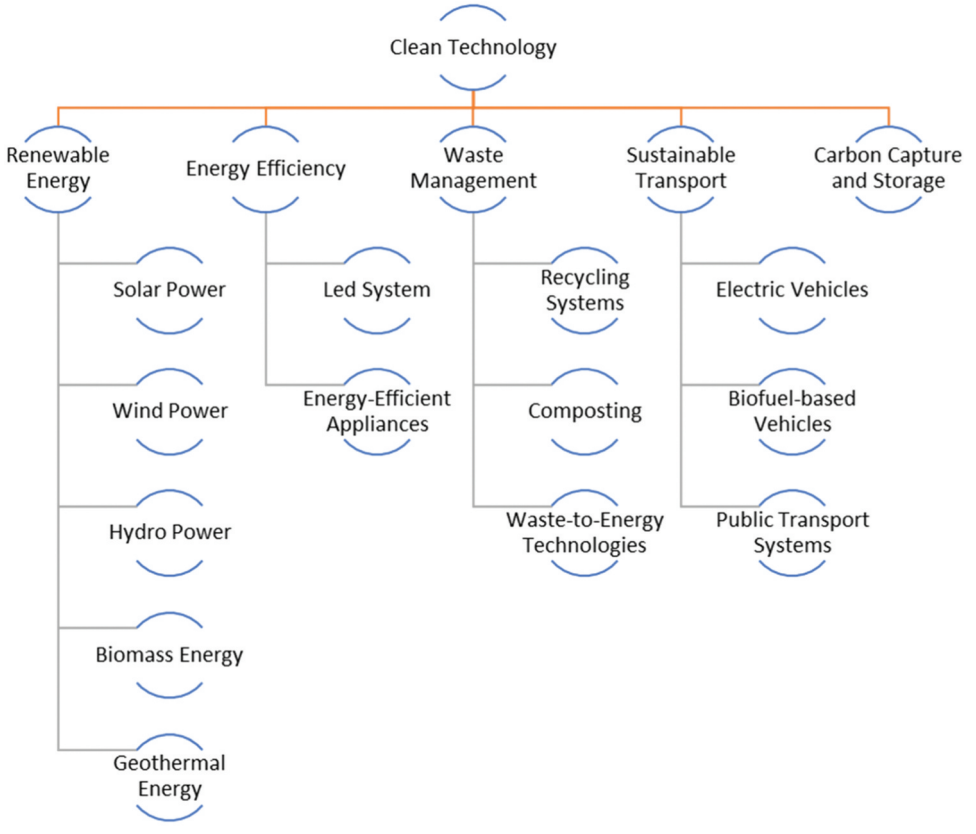


Figure 3. Structured definition of clean technology. Source: developed from literature review.

Figure 3 shows that cleantech takes on a diverse spectrum of meanings across various studies, with each interpretation spotlighting specific elements that align with their unique research goals. Bento, Gianfrate, and Groppo (2019) define cleantech as initiatives aimed at energy conservation, including material installation of energy plants and the manufacturing of products like LED systems and energy-efficient appliances. Cowling and Liu (2023) focus on businesses reducing their environmental impact through measures such as energy consumption reduction and waste reduction. Cumming, Leboeuf, and Schwienbacher (2017) adopt a broader approach, searching for terms related to green energy, cleantech, recycling, and various types of renewable energy in project descriptions.

Gaddy et al. (2017) define cleantech companies as those commercializing clean energy technologies or business models, including new materials, hardware, or software focused on energy generation, storage, distribution, and efficiency. Some, such as Owen et al. (2023) seek a broader definition of "Greentech", referring to technologies and associated business models and services that are environmentally positive and cover the full sustainability spectrum of activities which address climate (net zero), circular economy and biodiversity.

Drawing from these diverse perspectives (Figure 2), a holistic definition of clean technology could be proposed as follows: cleantech encompasses a broad range of

initiatives, technologies, and business models aimed at reducing environmental impact and promoting energy efficiency. This includes but is not limited to, the development and commercialization of energy-efficient products, renewable energy sources, waste reduction techniques, and new materials or software that enhance energy generation, storage, distribution, and efficiency. Further, cleantech is not limited to companies exclusively in the energy sector but also involves businesses across industries actively reducing their environmental footprint through various measures.

However, this focus also indicates a potential oversight of other sectors vital to sustainable development, such as sustainable transportation, green building, and sustainable fashion, which are equally crucial for achieving a comprehensive green transition. The emphasis on clean energy and agriculture, while significant, suggests a need to broaden the scope of research to encompass a wider array of sectors involved in green innovation.

3.2. Spatial concentration of literature

Geographical focus is primarily European, North American and advanced nations (Figure 4). It ranges widely, including specific countries such as Mali (Andrieu et al. 2017) and the UK (Cowling and Liu 2023; Owen 2023) to broader regions such as Europe (Bento, Gianfrate, and Groppo 2019; Masini and Menichetti 2013) and multi-country analyses (Cumming, Leboeuf, and Schwienbacher 2017; Deleidi, Mazzucato, and Semieniuk 2020).

As Figure 4 illustrates, country-specific research, particularly concentrated in the UK (Cowling and Liu 2023; Owen et al. 2023), the European Union (EU) (Bürer and Wüstenhagen 2009; Cecere, Corrocher, and Mancusi 2020; Ghisetti et al. 2017), and the

Figure 4. Global focus. Source: developed from literature review.

United States (US) (Hörisch and Tenner 2020; Marcus, Malen, and Ellis 2013), points to a geographical bias that overlooks the unique challenges and opportunities present in developing countries and emerging economies. Such a focus might inadvertently neglect the diverse financial ecosystems, regulatory environments, and innovation capacities that influence green finance innovation in different regions. For instance, the research conducted in Mali by Andrieu et al. (2017) stands out as a rare exploration into the African continent, highlighting the disparity in geographical coverage within the literature.

This sector and country bias, therefore, underscores a critical research gap: the need for more inclusive studies that address a broader spectrum of sectors and encompass a wider geographical diversity.

3.3. Methodological approaches

Figure 5 presents the distribution of research methodologies deployed. The preference for quantitative methodological approaches suggests a strong emphasis on empirical analysis to understand the impact, effectiveness, and dynamics of green finance innovation. Studies such as Andrieu et al. (2017), Cumming, Leboeuf, and Schwienbacher (2017), Cowling and Liu (2023), and Deleidi, Mazzucato, and Semieniuk (2020) utilize quantitative approaches to measure variables and test hypotheses, indicating a drive towards generating generalizable and statistically significant findings in the field of green finance and sustainability.

Qualitative methods – as deployed by Lam and Law (2016), Harrer and Owen (2022), and Owen (2023) – are primarily used to explore complex phenomena, understand the depth of issues, and gather insights on the motivations, perceptions, and challenges faced by stakeholders in green finance innovation. This approach is often exploratory, where insufficient large data exists in new emerging green innovation and also pivotal for capturing the nuanced aspects of green finance, which might not be readily quantifiable.

Hörisch and Tenner (2020) and Masini and Menichetti (2013) present attempts to leverage both qualitative and quantitative insights, showcasing the complexity and

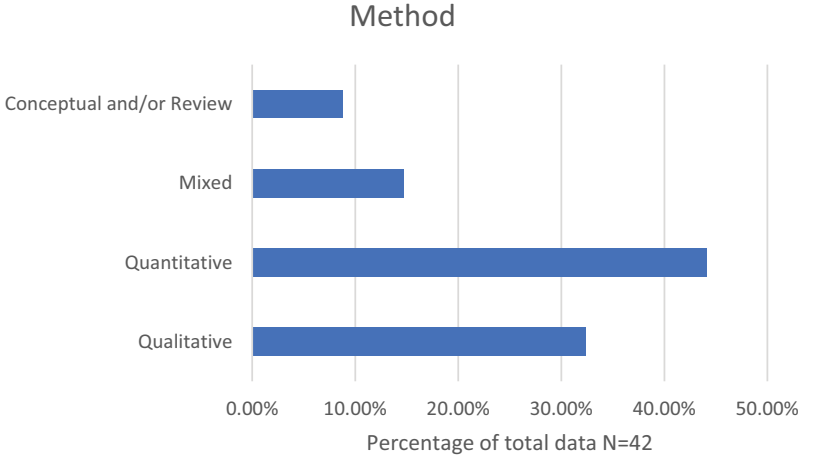


Figure 5. Research method. Source: developed from literature review.

multifaceted nature of green finance innovation research in their contrasting studies of the motivations of equity crowdfunders and formal and institutional investors.

Conceptual and/or review methods, though least used, can synthesize existing knowledge, proposing theoretical frameworks, and setting future research directions, as deployed by Foxon (2010) and Owen, Brennan, and Lyon (2018). These authors provide systematic frameworks, demonstrating the development of entrepreneurial finance ecosystems and ecological-technological "co-evolutionary" transition pathways shaping green innovation, finance and policy.

This methodological bias towards quantitative research, while contributing to the empirical rigor of the field, may not fully capture the rich, qualitative dimensions of green finance innovation, potentially limiting the depth of understanding and insight that can be gained. The deficit of mixed and conceptual methodologies demonstrates potential scope for more integrated mixed methods research and publication in this domain and extends beyond the call for improved data and more international comparative research.

3.4. Investor type and financing model

A diverse funding landscape for SMEs engaged in green innovation finance emerges, with a notable focus on venture capital (VC), crowdfunders, and banks (Figure 6). The presence of various funding sources, including public sector co-funding and private equity, underscores the multifaceted approach to financing green initiatives. This reflects the available literature bias towards well established European and North American finance markets (Owen, Brennan, and Lyon 2018). It is also notable that the predominant focus of green entrepreneurial finance papers has been on private sector sources, notably VC for earlier stage innovation finance (Owen 2023) and banks for established SME green transition financing (Cowling and Liu 2023).

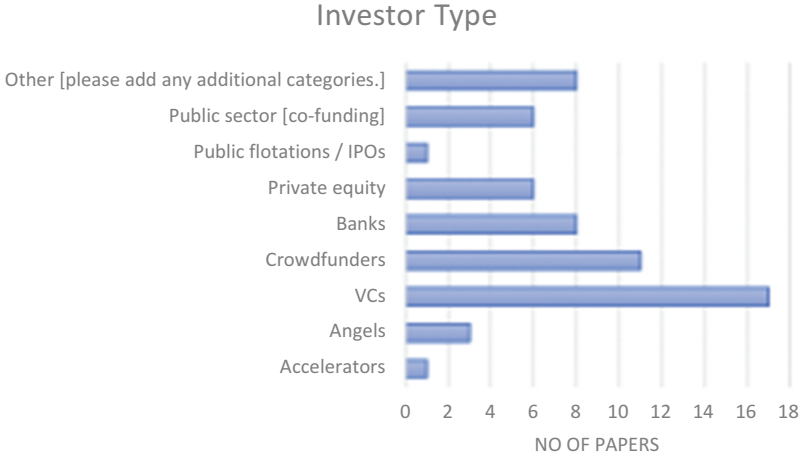


Figure 6. Investor type; X axis = No. Of papers; papers ($N = 42$) could focus on > 1 type of finance. Source: developed from literature review.

The significant rise of crowdfunding as an alternative form of green finance for early and established enterprise in recent years is reflected in the literature (Hörisch and Tenner 2020; O'Reilly, Mac an Bhaird, and Cassells 2023). However, relatively little has been written about business angel green finance (Botelho, Mason, and Chalvatzis 2023), despite this being the main source of early-stage finance in most developed countries (Mason and Harrison 2015).

This finding may be due to the lack of available large-scale data on business angel investment, which has led to more specialist, niche qualitative studies (Botelho, Mason, and Chalvatzis 2023; Siefkes, Bjorgum, and Sorheim 2023). Of particular concern is that only six papers examine public policy and green co-financing investment (e.g., Criscuolo and Menon 2015; Cumming, Henriques, and Sadorsky 2016; Mazzucato and Semieniuk 2018; Owen 2023; Owen and Vedanthachari 2023; Polzin, von Flotow, and Klerkx 2016). Given the need for sufficient financing to achieve global climate (net zero) and biodiversity (30 by 30) targets, this is an urgent area for more research and publications.

Additionally, the relatively lower frequency of public flotations/initial public offerings (IPOs) and accelerators suggests potential gaps in research on these sources for green finance innovation. The former demonstrates the decline of IPO markets globally since the Global Financial Crisis (GFC) (Baldock 2015), whilst the latter is indicative of the recent rise in green accelerators and venture studios, which remain under-researched (Pierrakis and Owen 2022). These issues are explored further in later sections of financing models.

3.5. Financing challenges

Early-stage innovation is typically difficult to finance due to the asymmetric knowledge differences which exist between entrepreneurs and prospective financiers (Carpenter and Petersen 2002) and the lack of collateral that small businesses possess to encourage external lending and investments (North, Baldock, and Ullah 2013).

Despite the urgent imperative to finance green-oriented initiatives, the reviewed papers reveal that they face multiple challenges that make it difficult to attract investors and secure funding. The literature frequently distinguishes cleantech as being different from mainstream innovation, since it is disruptive in terms of emerging technology, business models and largely reliant on expensive long horizon development (Harrer and Owen 2022). The eight main financing challenges identified in the literature (Table 1) are high capital costs and financing requirements, uncertain revenue streams, lack of access to traditional sources of financing, limited expertise and specialized knowledge, policy and regulatory barriers, limited public awareness, limited availability and accessibility of financing, and limited investment options.

One of the main and most frequently mentioned challenges (14 papers; Table 1) for cleantech and green-oriented initiatives is their high capital costs and financing requirements, particularly due to expensive long horizon hardware R&D and prototyping (Owen and Vedanthachari 2023). Bento, Gianfrate, and Groppo (2019) also note that low carbon technologies have distinct risk profiles, related to their emergent disruptive technologies and innovative business models. Their requirement for significant upfront investments can be a barrier to financing, especially for smaller and earlier stage businesses (Harrer and Owen 2022). This challenge is compounded by uncertain revenue streams due to fluctuations in energy prices or regulatory changes, making them less attractive to investors

Table 1. Investor type.

Financing Challenges	Studies
High capital costs and financing requirements	Bento, Gianfrate, and Groppo (2019); Botelho, Mason, and Chalvatzis (2023); Cowling and Liu (2023); Criscuolo and Menon (2015); Ghosh and Nanda (2010); Hörisch (2019); Lam and Law (2016); Marcus, Malen, and Ellis (2013); Mazzucato and Semieniuk (2018); Mrkajic, Murtinu, and Scalera (2019); Owen (2023); Owen and Vedanthachari (2023); Polzin et al. (2019); Polzin, von Flotow, and Klerkx (2016)
Uncertain revenue streams	Cowling and Liu (2023); Polzin et al. (2019)
Limited expertise and specialized knowledge	Cowling and Liu (2023); Hörisch (2015); Lam and Law (2016); Harrer and Owen (2022); Botelho, Mason, and Chalvatzis (2023); Siefkes, Bjorgum, and Sorheim (2023)
Policy and regulatory barriers	Criscuolo and Menon (2015); Ghisetti et al. (2017); Hörisch (2019); Hörisch and Tenner (2020); Mazzucato and Semieniuk (2018); Owen (2023)
Limited public awareness	Lam and Law (2016); Polzin et al. (2019)
Limited availability and accessibility of financing	Demirel and Parris (2015); Ghisetti et al. (2017); Marcus, Malen, and Ellis (2013); Owen and Vedanthachari (2023); Polzin, von Flotow, and Klerkx (2016); Polzin et al. (2019).

Source: developed from literature review.

(Cowling and Liu 2023; Polzin et al. 2019). Additionally, the disruptive, novel nature of cleantech projects may require specialized knowledge and expertise that may not be readily available to investors, making it difficult to evaluate the potential risks and returns of these projects (Cowling and Liu 2023; Hörisch 2015; Lam and Law 2016). Botelho, Mason, and Chalvatzis (2023), Harrer and Owen (2022) and Siefkes, Bjorgum, and Sorheim (2023) also consider that early-stage green impact investors, such business angels, may also require a degree of altruistic behavioural tendency, or "warm glow" (Hörisch and Tenner 2020), which leads them to trade-off some financial return in favour of longer horizon investment into environmental benefits. Investor knowledge and behavioural tendencies are also likely to be influenced by regulatory stability, environmental reporting requirements, and public investor and customer sentiment (Harrer and Owen 2022).

Cleantech and green-oriented initiatives face policy and regulatory barriers that are not conducive and may discourage investors from investing in these projects (Criscuolo and Menon 2015; Ghisetti et al. 2017; Hörisch 2019; Hörisch and Tenner 2020; Mazzucato and Semieniuk 2018; Owen and Vedanthachari 2023). For example, changes in government policies, regulations, or incentives can impact the financial viability of clean energy projects, making investors hesitant to commit funds (Polzin et al. 2019).

In addition, limited public awareness about the benefits of clean technology and the risks associated with climate change may also be a barrier to financing these projects (Lam and Law 2016; Polzin et al. 2019), reducing crowdfunding support and potential customer demand for cleantech products.

Another challenge is the lack of access to traditional sources of financing, such as bank loans, due to perceived risks and lack of collateral (Demirel and Parris 2015; Ghisetti et al. 2017; Polzin et al. 2019). Whilst this problem is more typical of mainstream early-stage innovation investment (North, Baldock, and Ullah 2013), cleantech may also suffer from over gearing of debt finance where they face long protracted R&D during their later stage scale-up, in relation to the patient capital funding gap that persists globally (Mazzucato and Semieniuk 2018). Cleantech and green-oriented initiatives may also face limited availability and accessibility of financing due to factors such as regional risk-equity financing disparities (Owen and Vedanthachari 2023), high uncertainty and risk, lack of

knowledge about innovation and finance, and difficulties in coordination and connection between different actors and policies (Polzin, von Flotow, and Klerkx 2016) and disparities of public co-financing policies (Owen et al. 2020).

Finally, cleantech and green-oriented initiatives may have limited investment options available, particularly in the early stages of development. This can be particularly challenging for Cleantech innovations viewed as high-risk investments (Marcus, Malen, and Ellis 2013; Polzin et al. 2019). Overall, addressing these financing challenges will require innovative financing mechanisms and policy frameworks to reduce risks and barriers associated with cleantech and green-oriented initiatives.

3.6. Financing model and mechanism

Despite increasing levels of green impact investment in cleantech through private VC, business angels and equity crowdfunding platforms in the post-GFC period (Hörisch and Tenner 2020; Owen et al. 2023), private investment is not shifting rapidly enough to meet the green innovation finance gap and accelerate sufficient solutions to achieve net zero 2050 targets. Thus, government "Green New Deal" type solutions are required (Owen et al. 2020), leading to a greater understanding of green entrepreneurial finance ecosystems and their interactions (Harrer and Owen 2022; Owen, Brennan, and Lyon 2018) and a requirement for wide ranging financial policy support instruments, investor incentives, co-financing arrangements, regulatory and support considerations. Furthermore, interventions are facilitating a more efficient green financing escalator linking new green venture studios with grants and subsequent early-stage equity and scale-up patient debt and equity capital (Owen 2023; Owen and Vedanthachari 2023; Owen et al. 2020).

VC has emerged as the major pivotal private source of equity financing for clean technology startups, offering not only necessary capital but also additional (non-financial assistance) managerial expertise and strategic networking opportunities. Cumming, Henriques, and Sadorsky (2016) and Migendt et al. (2017) explore the role of venture capital in supporting early-stage companies, emphasizing its importance in sectors characterized by high uncertainty and innovation. The VC model appears particularly suited to the clean technology industry, where the commercialization of new technologies often involves significant risk and long development timelines.

However, Gaddy et al. (2017) demonstrate that it is subject to poor performance during economic down cycles (such as the GFC) and question whether it is the right model for disruptive deeptech, leading others, such as Owen (2023) and Owen et al. (2020) to highlight the important role of public-private co-financing of VC to plug green investment gaps and develop a more robust, sustainable green VC market.

Equity financing, green bonds and other debt instruments have become key mechanisms for clean technology ventures to secure long-term capital. These instruments allow typically larger established firms to tap into public financial institutional instruments (e.g., UK Government Green Investment Bank bond funding for windfarm projects in the mid-2010s), stock markets and private institutional investment pools, offering a sustainable financing solution that aligns with environmental goals (Owen, Brennan, and Lyon 2018). Green bonds work effectively when designed for large capital projects with positive environmental impacts, providing an innovative approach to debt financing that can

lower capital costs and extend debt maturity for more established trading cleantech firms. McDaniels and Robins (2017) refer to Lloyds Bank's ESG bond for SME lending and Italy's Green Mini Bonds for SME growth. However, as Owen, Brennan, and Lyon (2018) point out, they rarely (in any global context, including World Bank projects in emerging economies) impact directly on smaller, earlier-stage green innovative ventures.

Public grants and subsidies support de-risking of early-stage projects and attracting subsequent private investment. By covering initial development costs and reducing financial risks, public funding plays a crucial role in the clean technology financing ecosystem (Criscuolo and Menon 2015; Polzin, von Flotow, and Klerkx 2016). This form of support is vital for R&D activities, prototype development, and facilitating market entry, thereby bridging the gap between innovative concepts and commercial viability. Owen and Vedanthachari (2023) highlight the importance of grants in supporting university green tech spin-outs through their initial proof of concept funding, whilst Owen (2023) draws on the experience of UK government grants for low carbon innovation and the need for these to be matched at an early stage by private equity investment. Focusing on the Innovate UK Investment Accelerator programme, which matches grants with VC and angel investors, she finds that this enables a more fluent operation of the early finance escalator, speeding up innovation progress and signalling both technological and commercial quality to improve later stage investment opportunities and success.

Crowdfunding and alternative finance models have introduced a democratized approach to funding, enabling a broader investor base to participate in clean technology ventures. Equity crowdfunding, peer-to-peer lending, reward and donation-based crowdfunding platforms have not only facilitated capital raising but also enhanced public engagement with clean technology projects (Hörisch 2019; O'Reilly, Mac an Bhaird, and Cassells 2023). These platforms serve the dual purpose of financing and marketing, increasing awareness and support among the general public and potential consumers. O'Reilly, Mac an Bhaird, and Cassells (2023) demonstrate that equity crowdfunding is highly appropriate for European cleantech, often at later seed stages where funding rounds are typically over 500,000 Euros for companies which are insufficiently established (in revenue) to attract private VC finance.

Despite the availability of these financing models, cleantech ventures face challenges, such as high capital costs and uncertain revenue streams, which are exacerbated by their lack of collateral to support traditional SME debt finance. Innovative solutions, including the establishment of green investment banks and the use of special-purpose vehicles (SPVs), are being explored to ring-fence funding to overcome these barriers (Mazzucato and Semieniuk 2018). Furthermore, the literature underscores the critical influence of policy and regulatory frameworks on the financing landscape for clean technology. Supportive policies, such as feed-in tariffs and renewable energy certificates, play a significant role in enhancing the attractiveness of cleantech investments, as highlighted by studies on the impact of governmental policy interventions (Ghisetti et al. 2017; Hörisch 2019). Owen's (2023) study of four different UK green public VC funds highlights the importance of public-private co-financing to leverage private investment into cleantech financing gaps along the early-stage green innovation investment finance escalator. Emerging discussions point towards the integration of sustainability into financial decision-making, with a growing interest in green environmental impact investing (e.g., Botelho, Mason, and Chalvatzis (2023): on the rise and motivations for business angel

green investment). This approach seeks to generate positive social and environmental impacts alongside financial returns, reflecting a broader shift towards sustainability in the investment community (Marcus, Malen, and Ellis 2013; Polzin et al. 2019).

In summary, the literature reveals a dynamic and evolving financing landscape for clean technology, characterized by a mix of traditional and innovative financial instruments, public policy support, and the rise of alternative finance models. These financing mechanisms collectively address the unique challenges faced by clean technology ventures, facilitating the development and commercialization of sustainable solutions.

3.7. Support ecosystem

Within the current landscape with diversity of finance, the support ecosystem for clean technology ventures is extensively defined by various institutional and structural supports that cater to the growth and development of these enterprises (Harrer and Owen 2022). A synthesis of the literature reveals a comprehensive framework of assistance from incubation facilities to policy-driven incentives.

Incubators and accelerators stand out as pivotal supports in providing clean technology startups with essential resources, including mentorship, business development services, and networking opportunities with investors and industry experts (Owen and Vedanthachari 2023; Pierrakis and Owen 2022). These entities accelerate startup growth by facilitating access to critical business knowledge and financial resources, thereby enhancing the commercial viability of innovative clean technology solutions. Universities and research institutions also play a significant role in the ecosystem, acting as a bridge between academic research and market application (Owen and Vedanthachari 2023). Through collaborations, patenting, and licensing agreements, they transfer knowledge and technology to the clean technology sector, fostering innovation and commercialization (Cumming, Henriques, and Sadorsky 2016). This relationship underscores the potential of academic institutions to drive forward clean technology advancements. Government programs and policies provide another layer of support, offering access to financing, regulatory guidance, and market entry assistance. Initiatives highlighted by Ghisetti et al. (2017) and Hörisch (2019) demonstrate the impact of public sector involvement on the clean technology landscape by providing vital resources such as grants, tax incentives, and R&D support. These efforts not only de-risk investments in clean technologies but also promote a favourable regulatory environment for their growth.

Non-governmental organizations (NGOs) and industry associations contribute by offering advocacy, networking, and knowledge exchange on sustainability practices (Harrer and Owen 2022; Owen, Brennan, and Lyon 2018). Their role in the ecosystem enriches clean technology ventures with insights into industry trends, regulatory frameworks, and sustainability standards, facilitating market integration and supply chain collaborations (Ghisetti et al. 2017; Hörisch 2019). Digital platforms and online communities have emerged as a modern component of the support ecosystem, enabling global access to mentors, investors, and collaborative opportunities. This digital expansion allows clean technology startups to transcend geographical limitations, fostering a broader network of support and innovation (Cowling and Liu 2023; Cumming, Henriques, and Sadorsky 2016).

In summary, the support ecosystem for clean technology ventures is characterized by a multi-faceted network of incubators, academic institutions, governmental programs,

NGOs, and digital platforms. Each element plays a crucial role in providing the necessary support for overcoming the challenges inherent in the clean technology sector, from technical and financial hurdles to market entry barriers. As this sector continues to evolve, the ongoing development and integration of these support mechanisms will be essential in nurturing sustainable innovations and facilitating the transition towards a greener economy.

3.8. Role of public sector in sustainability and cleantech development

Table 2 provides a summary of the key themes identified in the studies related to the role of the public sector in promoting sustainability and clean technology development and adoption. The studies collectively highlight the crucial role that the public sector plays in promoting a sustainable future by developing and implementing policies that prioritize the environment and promote cleantech innovation and the adoption of clean technologies.

The first theme identified in Table 2 is the role of the public sector in cleantech policy-making. Five studies emphasized the importance of creating cleantech policies that prioritize sustainability and the environment. These studies highlight the need for flexibility in central government targets to promote green transformation at the local level. Furthermore, they suggest that policy instruments should ensure funding resources are available throughout the lifecycle of clean technology development and adoption (Andrieu et al. 2017; Bürer and Wüstenhagen 2009; Cowling and Liu 2023).

The second theme (Table 2) is the role of the public sector in cleantech financing/investment. The review reveals the importance of targeted policy interventions to facilitate access to credit and mitigate capital market imperfections. The studies highlight the importance of reducing policy costs by reducing political risks, which, in turn, lowers financing costs (Ghisetti et al. 2017; Ghosh and Nanda 2010; Polzin et al. 2019). Ghosh and Nanda (2010) argue that VC investments in clean energy startups face unique structural challenges, particularly in relation to the timing of exits. These hurdles could potentially be overcome through policy interventions aimed at stimulating an active M&A market for clean energy startups. As the authors state, "*. . . a key aspect of the innovation ecosystem that will be required to make this sustainable will be to jumpstart an active M&A market for*

Table 2. The role of the public sector.

Key Themes	Studies
Role of public sector in sustainable environmental cleantech policy-making	Andrieu et al. (2017); Bürer and Wüstenhagen (2009); Cecere, Corrocher, and Mancusi (2020); Cowling and Liu (2023); Criscuolo and Menon (2015)
Role of the public sector in cleantech financing and investment	Cecere, Corrocher, and Mancusi (2020); Cowling and Liu (2023); Ghisetti et al. (2017); Ghosh and Nanda (2010) (Polzin et al. 2019); Polzin, von Flotow, and Klerkx (2016); Owen and Vedanthachari (2023); Owen et al. (2020); Owen (2023)
Role of public sector in promoting adoption and deployment of clean technology	Cowling and Liu (2023); Hargadon and Kenney (2012); Hörisch (2015, 2019); Mazzucato and Semieniuk (2018); Polzin, von Flotow, and Klerkx (2016)
Role of public sector in supporting crowdfunding for sustainable projects	Bento, Gianfrate, and Groppo (2019); Butticè et al. (2019)

Source: developed from literature review.

clean energy startups" (Ghosh and Nanda 2010, 20). Ghisetti et al. (2017, 143) stress the need for strategies to address capital market imperfections and facilitate credit access, stating; "*Targeting policy interventions to facilitate access to credit and to mitigate capital market imperfections . . . is crucial . . .* " Polzin et al. (2019, 1260) underline the effectiveness of risk-reducing and stable policies, asserting that; "*. . . reducing policy cost can be achieved through reducing political risks, which, in turn, lower financing cost. Policy predictability or stability is important in reducing risk*."

Additionally, these studies suggest that policymakers should coordinate early-stage cleantech innovation finance and attract private investors through feed-in tariffs and renewable portfolio standards (Bürer and Wüstenhagen 2009). The findings suggest that public sector support can accelerate the development of eco-innovations. Polzin et al. (2019, 1259) offer detailed insights from their extensive review of studies from more advanced global markets on the renewable energy sector on attracting private investors using policy instruments such as feed-in tariffs (FITs) and renewable portfolio standards (RPSs), noting; "*. . . instruments that reduce risk and provide high certainty for investors are particularly effective in triggering private investment*," especially FITs and RPSs. They also emphasize that these instruments need to be designed and implemented carefully to manage risks, and highlight the importance of credibility, i.e.; "*. . . no-retroactive changes*," as a key design feature (Polzin et al. 2019, 1259).

The third theme (Table 2) is the role of the public sector in promoting the adoption and deployment of clean technology. Cowling and Liu (2023), Hargadon and Kenney (2012), and Mazzucato and Semieniuk (2018) emphasize the importance of creating policies that provide tax incentives, subsidies, and regulatory frameworks that encourage investment in clean technologies. They also highlight the importance of accelerating the commercialization and diffusion of eco-innovations. The findings suggest that the public sector can play a crucial role in promoting innovation and entrepreneurship in the clean technology sector.

The final theme (Table 2) is the role of the public sector in supporting crowdfunding for sustainable projects. Bento, Gianfrate, and Groppof (2019), and Butticè et al. (2019) suggest that government support is crucial to promoting crowdfunding for sustainable projects. The studies suggest that governments of countries with an environmental sustainability orientation should support entrepreneurs in designing their crowdfunding campaigns.

Additionally, the studies suggest that the public sector can promote tools to advertise and share green-oriented campaigns among citizens, increasing the chances of obtaining the required funding. Bento, Gianfrate, and Groppo (2019) focus on equity crowdfunding and they emphasize that the government's role should be focused on disseminating information to potential investors (crowdfunders) to enhance the appeal and participation in such projects. They state; "*Policies should seek to reduce the perceived risk of new technologies, particularly the dissemination of information to crowdfunders in order to raise the incentives (including the allowed returns) and the level of participation*" (Bento, Gianfrate, and Groppo 2019, 114). On the other hand, Butticè et al. (2019) primarily examine reward-based crowdfunding and explore how the institutional setting of a country, particularly the environmental sustainability orientation, influences the emergence of green initiatives on crowdfunding platforms. Their study suggests; "*In these countries [with a strong environmental sustainability orientation], policy makers would better abstain from subsidizing green crowdfunding campaigns, if they do not want to incur in the*

risk of subsidizing lower quality projects, and would better resort to other forms of support to green initiatives" (Butticè et al. 2019, 3).

In conclusion, the studies suggest that the public sector plays a crucial role in promoting sustainability and cleantech innovation development and adoption, which are interrelated. Indeed, conducive green policy mix (Uyarra, Shapira, and Harding 2016) of regulations and finance incentives to support cleantech adoption stimulate the cleantech innovation market (Cowling and Liu 2023; Owen and Vedanthachari 2023).

4. Discussion

This Systematic Literature Review (SLR) sought to fill a gap in academic, policy and practitioner knowledge relating to how SME green innovation and cleantech are currently financed and to understand the barriers which prevent more rapid development of potentially game-changing solutions that can address climate change, circular economy and nature positive requirements for a sustainable green global economy. In doing so, this review addresses the calls to progress SME green innovation finance research (Mazzucato and Semieniuk 2018; Owen et al. 2023). We recognized the need for a more holistic systems approach that could bring together relevant contemporary research to deliver theoretical contribution to the development of green innovation entrepreneurial finance ecosystems and policy contribution.

Our review clearly demonstrates how the investment in early-stage and scale-up stages of green innovation and cleantech SMEs are different and more complex than mainstream innovation investment. This is inherently due to their disruptive and unknown outcomes, associated with emerging, mainly high capital-intensive long horizon hardware technologies (Mazzucato and Semieniuk 2018; Owen and Vedanthachari 2023). It is also due to the duality of their business models (Harrer and Owen 2022), which require investors to consider public good as well as financial return (Polzin 2017). The literature review reveals a complex array of financiers, both private and public, with highly specialized financial intermediary skills required to assess these innovations.

There are also a range of policy initiatives and support providers. Yet, these are often disconnected, even in the more mature green finance markets of Europe and North America (Owen and Vedanthachari 2023). This green finance disconnection suggests the need for research to understand the interrelationships between policy, private investment and intermediary structures (Polzin, von Flotow, and Klerkx 2016) and how SME cleantech finance progresses along the emerging green innovation finance escalator. This need was revealed in the nascent and expanding approaches of academic literature in this field which exposed critical knowledge gaps in theory building.

Defining cleantech, the limitations of current SME green finance quantitative data and limited development of qualitative and mixed method approaches all reveal requirements for improved understanding of the underlying connections and behaviours of green impact investors towards cleantech SMEs. Whilst this leads to a series of important theoretical contributions, addressed first in our discussion, it also highlights the vital role that public policy plays in stimulating green innovation and determining the likely success of financial policy programmes (Mazzucato and Semieniuk 2018; Polzin et al. 2019). Our review hence contributes to SME cleantech policy in presenting a clearer direction for integrated policy programme roadmaps (Owen et al. 2023).

4.1. Theoretical contribution

The first fundamental contribution is to establish a clear definition of green innovation and "cleantech". Whilst our review revealed multiple definitions, these were clearly driven from the conceptual requirements of specific studies, notably renewable energy and material-based views (Gaddy et al. 2017) and the domination of advanced tech nation studies in North America and Europe (Ghosh and Nanda 2010). Yet there is a need for a broader definition of green innovation and cleantech which embraces all green environmentally positive tech (i.e., which increases energy efficiency and reduces environmental impact), including farming, circular economy and biodiversity. Indeed, it would be helpful from an economic accounting perspective for more specific industry verticals such as ag-tech, nature-tech and climate-tech, whilst forming their own distinctive tech sub-categories, to be specifically defined under the umbrella of "cleantech" and recognition of the wider green innovation-related services and consumer behaviour change. This revised definition would facilitate an improved overview of the SME cleantech market and also future comparative studies between tech verticals.

A second contribution outlines the diversity of economic theories which are adopted by studies of financing cleantech innovation. These range from Andrieu et al'.s (2017) adoption of economic growth theory applied to an African context to Cowling and Liu's (2023) use of demand-pull and regulatory push-pull theories or Deliedi, Mazzucato and Semieniuk's (2020) macro-economic crowding in or out appraisal of public investment. These recognise the important role of the public sector and the latter study points to the need for research which incorporates understanding of the theories of change and dynamic capabilities of bottom-up learning, suggesting a need for mixed methods and more qualitative research. These theories of change show how investors in green innovation are driven by multiple rationales including financial return but also environmental impacts. In this way, they are seeing investment as a commitment to future generations rather than solely short-term profit.

A third contribution is, therefore, revealed in the deficit of academic literature relating to qualitative understanding of investor behaviour. Notably, this understanding is required to explain the rise in green impact investment in early-stage crowdfunding, business angel and seed VC, where investor data remains difficult to obtain. The emergence of small-scale qualitative behavioural finance studies (Botelho, Mason, and Chalvatzis 2023; Siefkes, Bjorgum, and Sorheim 2023) which examine cognitive biases and institutional logics (e.g Masini and Menichetti 2013) offer a promising entry point, particularly if combined with entfin ecosystem approaches. Such systems approaches would bring together the different actors – entrepreneurs, public and private investors and SME support services (including R&D institutions, universities, legal, accounting, access to finance) – which contribute to financing networks. Research would then progress beyond the current vision of institutional logics and entfin ecosystem of Harrer and Owen (2022) and Owen and Vedanthachari (2023). It would lead to greater potential for developing mixed method approaches for bringing together qualitative and quantitative research. It would also encourage interdisciplinary studies to explore the behavioural ("nudge") impacts of policy, which is demonstrably under-represented and constraining the required ecosystem theory building (Hruskova 2024).

A fourth contribution is the clear articulation for why SME early-stage cleantech innovation is more problematic than mainstream early innovation. This explanation relates to the scale of high-risk funding required (Mazzucato and Semieniuk 2018) and the disruptive nature of new green business models which require specialist investor tech knowledge and also a trade-off for public good which may not be met by the private sector alone (Polzin 2017). Here there is an emergent and clear call for innovative private and public financing approaches to address finance escalator private finance failure gaps (Owen et al. 2023). These relate to the nature of emerging disruptive cleantech, which are high risk, particularly in early-stage development, and frequently hardware development oriented, which require large multi-million investment and patient long horizon capital for pilot developments (Harrer and Owen 2022; Mazzucato and Semieniuk 2018; Owen and Vedanthachari 2023). Our review spotlights the need for public intervention, yet such cleantech financing programmes are not effective in isolation, unless they are carefully integrated to create more fluent financing through early and scale-up stages (Owen 2023; Owen, Brennan, and Lyon 2018) and more holistic policies which address SME support and address local (regional) disparities in the availability of finance (Uyarra, Shapira, and Harding 2016).

Extending the holistic requirement, a fifth theoretical contribution is to bring together five emerging cleantech literature themes (investor types, financing challenges, financing models, support ecosystem and policy) which underpin the need for an integrated systems approach to understanding the green innovation entrepreneurial finance ("entfin") ecosystem. This entfin ecosystem approach revealed innovative private sector solutions such as crowdfunding, accelerators, green environmental impact business angel networks and seed VC. It also revealed problems of agency, environmental legitimacy (Hörisch 2019) and sustainability signalling (Mrkajic, Murtinu, and Scalera 2019) which exist between entrepreneurs and investors. These support ecosystems involving investors, advisers and policy makers are part of the wider purposeful business ecosystems that are emerging as businesses seek to address a range of environmental and social purposes (Lyon et al. 2024).

Thus, despite the rise of crowdfunding, such uncertainties result in continuing private investment shortfalls in meeting cleantech external financing requirements and, therefore, the need for public policy support. Our review encountered novel public-private co-financing to reduce early-stage risk and encourage greater syndication, pointing to the need for early-stage public grants through universities and innovation agencies to leverage private seed investment early in the cleantech external funding process in order to signal technical and commercial certification and alignment to later-stage investors (Owen 2023).

The review also demonstrated that the availability of public and private finance will not be effective without supportive public policy which provides regulatory and financial incentive stability, such as for renewable energy (Bürer and Wüstenhagen 2009; Petkova et al. 2014) and for regional outreach and financial connectivity (Cowling and Liu 2023). This final point is crucial for smaller economies, which require the external finance market outreach for scale-up, particularly in the case of cleantech, where scale-up funding requirements are often substantial (Mazzucato and Semieniuk 2018). Here there is strong evidence from this review to suggest that large-scale patient capital requires a combination of public funding collaboration between countries and also through international R&D and Corporate VC linkages (Owen and Vedanthachari 2023).

4.2. Policy contribution

From a policy perspective, the main contribution of this review is to build on the calls for more cohesive and integrated governance of sustainability and cleantech innovation entrepreneurial finance (Butticè et al. 2019; Owen 2023; Owen et al. 2023; Uyarra, Shapira, and Harding 2016). This policy connection extends from regional and local finance pipelines to international programmes which offer market scale opportunities and reduce thin market funding programme failures (Owen 2023; Owen, Brennan, and Lyon 2018 – a notable successful low carbon investment model was the global UK Innovation Investment Fund). Whilst a considerable amount of policy literature has come from UK and EU studies, where SME green innovation, notably low carbon, public support programmes have been most prevalent, key lessons from these markets need to be examined in a wider global context.

Primarily, progressing beyond these studies to the establishment of clear roadmaps for SME cleantech financing which embrace holistic policies of SME support and outreach and which work to bring together the range of private financiers and support services and agencies along the finance escalator, should enable public programmes and policy instruments to integrate more effectively. This process requires public institutional structures providing specialist oversight into SME green finance, such as Green Investment Banks and overarching green bond structures that can leverage the large-scale private institutional investment (from banks, pension funds, large corporations and trusts) required to address Earth's environmental repair (Mazzucato and Semieniuk 2018). However, beyond this narrow financial policy process there is also a growing awareness that wider public policies which relate to consumer behaviour and public sentiment, such as feed-in-tariffs and the environmental auditing and reporting of larger corporate businesses and local authorities which impose green supply-chain reporting are also crucial (Bürer and Wüstenhagen 2009). Furthermore, studies on early-stage investment behaviour strongly support the need for positive government signalling through stable long-term institutions (which can outlast shorter-term national governments) and policy and regulatory environments which give cleantech sector legitimation which encourage the uptake of new clean technologies, like renewable energy and electric vehicles (Petkova et al. 2014). However, no prior study provides such an overall blueprint for the policy roadmap of SME cleantech financing and support as offered here (Figure 7).

4.3. Limitations reported in existing literature

Our review of the literature reveals three key limitations of the existing body of literature relating to data quality, understanding complexity, and generalizability. Whilst these limitations are common problems for most academic studies, they demonstrate particularly concerning issues for SME green entfin researchers, practitioners and policymakers who want to avoid environmental catastrophe. O'Reilly, Mac an Bhaird, and Cassells (2023) point to a lack of transparency of data, which is blurred by inconsistent approaches to definitions of cleantech and also prevents private and public investor assessment of public good. Data limitations on small businesses have been further exacerbated by the global lack of SME environmental reporting mechanisms and national surveys which incorporate green finance. This data limitation led Hörisch and Tenner (2020) to highlight

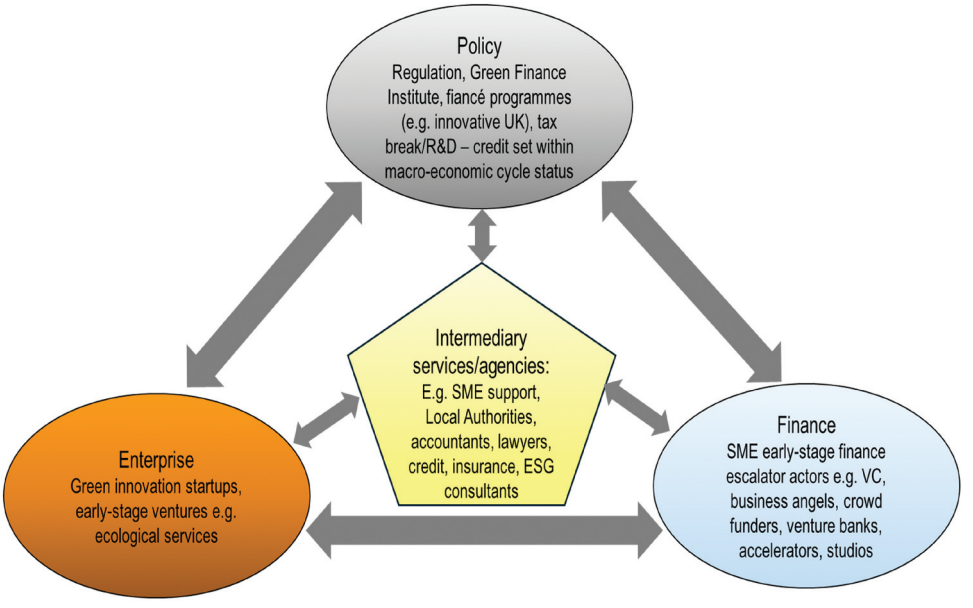


Figure 7. Proposed early-stage entfin ecosystem (UK example). Source: Owen et al. (2024).

their inability to benchmark data and to generalize research findings. Similarly, Bento, Gianfrate, and Groppo (2019) and Botelho, Mason, and Chalvatzis (2023) focus on the paucity of current data on green investor decision-making, whilst Harrer and Owen (2022) point to the inconsistent measurements of environmental impact, due to complexity and sectoral and business materiality nuances which currently hamper green investment screening and monitoring.

There is a lack of research exploring the complexity of early stage green finance with multiple indicators or impact, multiple actors and a rapidly changing context. Not surprisingly, complexity has led to specialist studies, which primarily focus on specific business sectors (Deleidi, Mazzucato, and Semieniuk 2020), innovation stages (Owen and Vedanthachari 2023), single stakeholder investor types (Botelho, Mason, and Chalvatzis 2023) and policy actors (Owen 2023).

Finally, there are limitations regarding generalizations and drawing wider conclusions. Studies are typically focused on mature European and North American economies, with few insights or practical recommendations for emerging markets. The lack of generalizability of studies suggests the need for a more holistic entrepreneurial finance ("entfin") ecosystems approach to understanding the evolution and operation of the green finance.

4.4. Future research

This SLR offers widespread consensus for the need for further research into SME cleantech financing as a key to delivering the environmental sector solutions for achieving Net Zero and wider global environmental goals. Research should focus on the development of nascent cleantech sectors. Existing studies reveal that emerging cleantech is complex,

with limited existing data on the economic and environmental impacts of new cleantech and their related public finance and support policies.

Cleantech financing has required new emerging highly specialist environmental impact investors with sector/vertical expertise who are prepared to invest in very high-risk, but potentially high-return early-stage ventures (Owen and Vedanthachari 2023). It has also led to new financing models, particularly in the form of syndication to share risk amongst, for example, angel networks (Botelho, Mason, and Chalvatzis 2023), crowdfunders (O'Reilly, Mac an Bhaird, and Cassells 2023) and various forms of public-private co-financing (Owen 2023) and public grants and subsidies (Cowling and Liu 2023) to reduce risk and crowd-in private investment (Olmos, Ruester, and Liong 2012). However, financing gaps persist along the emerging green finance escalator, particularly for initial equity investment and for commercial scale-up (Owen and Vedanthachari 2023) suggesting a need for improved research data on cleantech markets, their investors and the impacts of public policies to find what works, where and how. Given the paucity of cleantech research in emerging markets (Awan, Arnold, and Gölgeci 2021; Criscuolo and Menon 2015; Owen 2023; Owen, Brennan, and Lyon 2018), more studies are required to build up the emerging market evidence base to discover specific solutions and also what may be generalizable and transferable.

The studies highlight the role of public policy to stimulate investment for public good. A key focus is therefore to understand the appropriate public policy mix (Uyarra, Shapira, and Harding 2016) to address investor uncertainty through de-risking the market with stable regulation, consistent public financial stimulus instruments (e.g., grants, subsidies, co-funding; Owen et al. 2023), investor skills support (Andrieu et al. 2017) and enabling access to skills for cleantech R&D (Cumming, Henriques, and Sadorsky 2016). Further research needs to establish how to create a stable, sustainable cleantech investment market which encourages risk capital such as through VC (Cumming, Leboeuf, and Schwienbacher 2017) and the crowding-in of private investment which can include crowdfunding (Olmos, Ruester, and Liong 2012).

The above demands new research to offer overarching policy systems approaches to nurture and scaleup cleantech, through on the one hand localized (regional) early-stage cleantech entfin ecosystem support structures and, on the other hand, national and multinational green finance institutions that oversee more broadly the green finance escalator. More specifically, the lack of data on cleantech funding (Cowling and Liu 2023), including types of investors and their green investment preference behaviours (Botelho, Mason, and Chalvatzis 2023), new emerging models of financing such as crowdfunding (O'Reilly, Mac an Bhaird, and Cassells 2023), public-private co-finance (Owen 2023) and public subsidies (Foxon 2010; Hörisch and Tenner 2020); and measurement of the resultant cleantech environmental all form crucial parts of the future cleantech research paradigm. Here, it is important to note the lack of mixed methods studies which can bring together large data with case-specific understanding, particularly with respect to green investor preferences which can assist public policy and unlocking more private investment.

This SLR offers clear direction and distinctive requirements for the advancement of cleantech research. Primarily, the acknowledged shortcomings of the current literature suggest the need for a more coherent research framework, which embraces the promising green entfin ecosystem approach proposed. This would help to build bottom-up, greater

understanding of the interactions between actors and support larger scale qualitative case and location analysis, offering qualitative research frameworks to support specific policy and practice environments. Such approaches can respond to the calls for analysing different cleantech financing models (Cumming, Henriques, and Sadorsky 2016) and the effectiveness of policies such as tax incentives, public-private co-financing and regulation (Cumming, Leboeuf, and Schwienbacher 2017; Olmos, Ruester, and Liong 2012; Owen 2023).

5. Conclusion

This SLR addresses the current policy salience of supporting green technology innovation as a pathway to achieving global environmental sustainability. We focus on the potential role of SME cleantech to deliver environmentally positive game changing innovations and provide the first comprehensive SLR of cleantech early-stage innovation financing. As with all SLR, there are limitations from having a focus on established and highly cited journals. This can exclude emerging research published elsewhere.

Our review reveals the paucity of data and bias of the small extant collection of literature on more mature North American and European entfin ecosystems. Whilst we find an abundance of new forms of private finance within the emerging early-stage SME green innovation finance escalator in the post-GFC period, there is also heavy reliance on public gap funding and a lack of evidence of its impacts. Furthermore, cleantech characteristics for disruptive high capital expenditure long horizon deeptech require extensive and innovative public financing instruments and policies to create the stable and supportive market to reduce risk and encourage greater early-stage private investing.

We reveal strong requirements for research and policy to work together in an interdisciplinary fashion to develop more holistic entfin ecosystem research which addresses theory of change and stakeholder perspectives for financing cleantech. This systems theory building, embracing quantitative economic development and qualitative behavioural finance theory-based research, offers potential solutions to closing the gap on cleantech information asymmetries. It can lead to a more effective green economy policy mix and improved public-private co-financing and related stakeholder support policies. Furthermore, it can more readily provide the policy evidence base for what works in what context, enabling transnational and emerging market green economy finance learning and application – providing more fluent and efficient cleantech funding escalators globally and enabling their more rapid commercial application to meet planetary sustainability targets.

Acknowledgement

We would like to acknowledge research assistance from Dr Harjit Roberts.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the University of Waikato under Grant [Waikato Management School contestable fund] and Economic and Social Research Council, Grant/Award Number: ES/M010163/1.

References

'*Mobilizing Sustainable Finance for Small and Medium Sized Enterprises', UNEP Inquiry into the Design of a Sustainable Financial System*. Genever: United Nations Environmental Programme. April.

Andrieu, N., B. Sogoba, R. Zougmore, F. Howlan, O. Samake, M. Bonillsa-Findji, A. Lizarazo, Nowak, C. Dembele, and C. Corner-Dolloff. 2017. "Prioritizing Investments for Climate-Smart Agriculture: Lessons Learned from Mali." *Agricultural Systems* 154:13–24. https://doi.org/10.1016/j.agsy.2017.02.008.

Awan, U., M. G. Arnold, and I. Gölgeci. 2021. "Enhancing Green Product and Process Innovation: Towards an Integrative Framework of Knowledge Acquisition and Environmental Investment." *Business Strategy and the Environment* 30 (2): 1283–1295. https://doi.org/10.1002/bse.2684.

Baldock, R. 2015. "What is the Role of Public Feeder Markets in Developing Technology-Based Small Firms? An Exploration of the Motivations for Listing on AIM Since the GFC." *Venture Capital: An International Journal of Entrepreneurial Finance* 17 (1–2): 87–112. https://doi.org/10.1080/13691066.2015.1021028.

Bento, N., G. Gianfrate, and S. V. Groppo. 2019. "Do Crowdfunding Returns Reward Risk? Evidences from Clean-Tech Projects." *Technological Forecasting & Social Change* 141:107–116. https://doi.org/10.1016/j.techfore.2018.07.007.

Botelho, T., C. Mason, and K. Chalvatzis. 2022. "50 Shades of Green—Angel Investing in Green Businesses." *IEEE Transactions on Engineering Management* 70 (3): 950–962. https://doi.org/10.1109/TEM.2022.3167282.

Bürer, M. J., and R. Wüstenhagen. 2009. "Which Renewable Energy Policy is a Venture Capitalist's Best Friend? Empirical Evidence from a Survey of International Cleantech Investors." *Energy Policy* 37 (12): 4997–5006. https://doi.org/10.1016/j.enpol.2009.06.071.

Butticè, V., M. G. Colombo, E. Fumagalli, and C. Orsenigo. 2019. "Green Oriented Crowdfunding Campaigns: Their Characteristics and Diffusion in Different Institutional Settings." *Technological Forecasting & Social Change* 141:85–97. https://doi.org/10.1016/j.techfore.2018.07.047.

Carpenter, R. E., and B. C. Petersen. 2002. "Capital Market Imperfections, High-Tech Investment, and New Equity Financing." *The Economic Journal* 112 (477): F54–F72. https://doi.org/10.1111/1468-0297.00683.

Cecere, G., N. Corrocher, and M. L. Mancusi. 2020. "Financial Constraints and Public Funding of Eco-Innovation: Empirical Evidence from European SMEs." *Small Business Economics* 54 (1): 285–302. https://doi.org/10.1007/s11187-018-0090-9.

Cowling, M., and W. Liu. 2023. "Access to Finance for Cleantech Innovation and Investment: Evidence from U.K. Small- and Medium-Sized Enterprises." *IEEE Transactions on Engineering Management* 70 (3): 963–978. https://doi.org/10.1109/TEM.2021.3066685.

Criscuolo, C., and C. Menon. 2015. "Environmental Policies and Risk Finance in the Green Sector: Cross-Country Evidence." *Energy Policy* 83:38–56. https://doi.org/10.1016/j.enpol.2015.03.023.

Cumming, D. J., I. Henriques, and P. Sadorsky. 2016. "Cleantech Venture Capital Around the World." *International Review of Financial Analysis* 44:86–97. https://doi.org/10.1016/j.irfa.2016.01.015.

Cumming, D. J., G. Leboeuf, and A. Schwienbacher. 2017. "Crowdfunding Cleantech." *Energy Economics* 65:292–303. https://doi.org/10.1016/j.eneco.2017.04.030.

Deleidi, M., M. Mazzucato, and G. Semieniuk. 2020. "Neither Crowding in nor Out: Public Direct Investment Mobilising Private Investment into Renewable Electricity Projects." *Energy Policy* 140:111195. https://doi.org/10.1016/j.enpol.2019.111195.

Demirel, P., and S. Parris. 2015. "Access to Finance for Innovators in the UK's Environmental Sector." *Technology Analysis & Strategic Management* 27 (7): 782–808. https://doi.org/10.1080/09537325.2015.1019849.

Foxon, T. J. 2010. "Stimulating Investment in Energy Materials and Technologies to Combat Climate Change: An Overview of Learning Curve Analysis and Niche Market Support." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 368:3469–3483. https://doi.org/10.1098/rsta.2010.0106.

Gaddy, B. E., V. Sivaram, T. B. Jones, and L. Wayman. 2017. "Venture Capital and Cleantech: The Wrong Model for Energy Innovation." *Energy Policy* 102:385–395. https://doi.org/10.1016/j.enpol.2016.12.035.

Ghisetti, C., S. Mancinelli, M. Mazzanti, and M. Zoli. 2017. "Financial Barriers and Environmental Innovations: Evidence from EU Manufacturing Firms." *Climate Policy* 17 (sup1): S131–S147. https://doi.org/10.1080/14693062.2016.1242057.

Ghosh, S., and R. Nanda. 2010. "Venture Capital Investment in the Clean Energy Sector." *Harvard Business School Entrepreneurial Management Working Paper, No. 11-020*. https://doi.org/10.2139/ssrn.1669445.

Hargadon, A. B., and M. Kenney. 2012. "Misguided Policy? Following Venture Capital into Clean Technology." *California Management Review* 54 (2): 118–139. https://doi.org/10.1525/cmr.2012.54.2.118.

Harrer, T., and R. Owen. 2022. "Reducing Early-Stage Cleantech Funding Gaps: An Exploration of the Role of Environmental Performance Indicators." *International Journal of Entrepreneurial Behavior and Research* 28 (9): 268–288. https://doi.org/10.1108/IJEBR-10-2021-0849.

Hörisch, J. 2015. "Crowdfunding for Environmental Ventures: An Empirical Analysis of the Influence of Environmental Orientation on the Success of Crowdfunding Initiatives." *Journal of Cleaner Production* 107:636–645. https://doi.org/10.1016/j.jclepro.2015.05.046.

Hörisch, J. 2019. "Take the Money and Run? Implementation and Disclosure of Environmentally-Oriented Crowdfunding Projects." *Journal of Cleaner Production* 223:127–135. https://doi.org/10.1016/j.jclepro.2019.03.100.

Hörisch, J., and I. Tenner. 2020. "How Environmental and Social Orientations Influence the Funding Success of Investment-Based Crowdfunding: The Mediating Role of the Number of Funders and the Average Funding Amount." *Technological Forecasting & Social Change* 161:120311. https://doi.org/10.1016/j.techfore.2020.120311.

Hruskova, M. 2024. "Ecosystem Pipelines: Collective Action in Entrepreneurial Ecosystems." *International Small Business Journal* 42 (1): 39–66. https://doi.org/10.1177/02662426231178381.

IPCC (Intergovernmental Panel on Climate Change). 2022. "Climate Change 2022: Mitigation of Climate Change Summary for Policymakers," Intergovernmental Panel on Climate Change (IPCC), Working Group III Contribution to the Sixth Assessment Report, 978-92-9169-160-9, *IPCC*. Cambridge: Cambridge University Press. Accessed November 8, 2022. ISBN 978-92-9169-160-9, https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_ AR6_WGIII_SPM.pdf.

IPCC (Intergovernmental Panel on Climate Change. 2023. Synthesis Report of the IPCC Sixth Assessment Report (AR6): Summary for Policymakers. Interlaken, Switzerland: IPCC.

Lam, P. T. I., and A. O. K. Law. 2016. "Crowdfunding for Renewable and Sustainable Energy Projects: An Exploratory Case Study Approach." *Renewable and Sustainable Energy Reviews* 60:11–20. https://doi.org/10.1016/j.rser.2016.01.046.

Lyon, F., W. Stubbs, F. Dahlmann, and M. Edwards. 2024. "From "Business as Usual" to Sustainable "Purpose-Driven Business": Challenges Facing the Purpose Ecosystem in the United Kingdom and Australia." *Business and Society Review* 1–24. https://doi.org/10.1111/basr.12341.

Marcus, A., J. Malen, and S. Ellis. 2013. "The Promise and Pitfalls of Venture Capital as an Asset Class for Clean Energy Investment: Research Questions for Organization and Natural Environment Scholars." *Organization & Environment* 26 (1): 31–60. https://doi.org/10.1177/1086026612474956.

Masini, A., and E. Menichetti. 2013. "Investment Decisions in the Renewable Energy Sector: An Analysis of Non-Financial Drivers." *Technological Forecasting & Social Change* 80 (3): 510–524. https://doi.org/10.1016/j.techfore.2012.08.003.

Mason, C. M., and R. T. Harrison. 2015. "Business Angel Investment Activity in the Financial Crisis: UK Evidence and Policy Implications." *Environment and Planning C: Government & Policy* 33 (1): 43–60. https://doi.org/10.1068/c12324b.

Mazzucato, M., and G. Semieniuk. 2018. "Financing Renewable Energy: Who is Financing What and Why it Matters." *Technological Forecasting & Social Change* 127:8–22. https://doi.org/10.1016/j.techfore.2017.05.021.

Migendt, M., F. Polzin, F. Schock, F. A. Täube, and P. von Flotow. 2017. "Beyond Venture Capital: An Exploratory Study of the Finance-Innovation-Policy Nexus in Cleantech." *Industrial and Corporate Change* 26 (6): 973–996. https://doi.org/10.1093/icc/dtx014.

Mrkajic, B., S. Murtinu, and V. G. Scalera. 2019. "Is Green the New Gold? Venture Capital and Green Entrepreneurship." *Small Business Economics* 52 (4): 929–950. https://doi.org/10.1007/s11187-017-9943-x.

Nanda, R. 2020. "Financing Tough Tech Innovation." In *Global Innovation Index 2020: Who Will Finance Innovation?* edited by S. Dutta, B. Lanvin, and S. Wunsch-Vincent, 113–119. New York: Cornell University, INSEAD and World Intellectual Property Organization (WIPO).

North, D., R. Baldock, and F. Ullah. 2013. "Funding the Growth of UK Technology-Based Small Firms Since the Financial Crash: Are There Breakages in the Finance Escalator?" *Venture Capital: An International Journal of Entrepreneurial Finance* 15:237–260. https://doi.org/10.1080/13691066.2013.804755.

Olmos, L., S. Ruester, and S.-J. Liong. 2012. "On the Selection of Financing Instruments to Push the Development of New Technologies: Application to Clean Energy Technologies." *Energy Policy* 43:252–266. https://doi.org/10.1016/j.enpol.2012.01.001.

O'Reilly, S., C. Macan Bhaird, and D. Cassells. 2023. "Financing Early Stage Cleantech Firms." *IEEE Transactions on Engineering Management* 70 (3): 991–1005. https://doi.org/10.1109/TEM.2021.3095373.

Owen, R. 2023. "Lessons from Government Venture Capital Funds to Enable Transition to a Low-Carbon Economy: The U.K. Case." *IEEE Transactions on Engineering Management* 70 (3): 1040–1054. https://doi.org/10.1109/TEM.2021.3094992.

Owen, R., T. Botelho, J. Hussain, Y. Pierrakis, J. Scott, and S. Lodh. 2023. "Editorial Entrepreneurial Finance for Green Innovative SMEs." *IEEE Transactions on Engineering Management* 70 (3): 942–949. https://doi.org/10.1109/TEM.2022.3224870.

Owen, R., G. Brennan, and F. Lyon. 2018. "Enabling Investment for the Transition to a Low Carbon Economy: Government Policy to Finance Early Stage Green Innovation." *Current Opinion in Environmental Sustainability* 31:137–145. https://doi.org/10.1016/j.cosust.2018.03.004.

Owen, R., A. Burnett, F. Lyon, and A. Werner. 2024. "SME Nature Positive Finance." Paper presentation at the Natural Environment Research Council Integrated Finance and Biodiversity conference, Nottingham, January.

Owen, R., O. Lehner, F. Lyon, and G. Brennan. 2020. "Early Stage Investing in Green SMEs: The Case of the UK." *ACRN Journal of Finance and Risk Perspectives* 8 (1): 163–182. https://doi.org/10.35944/jofrp.2019.8.1.011.

Owen, R., and L. Vedanthachari. 2023. "Exploring the Role of U.K. Government Policy in Developing the University Entrepreneurial Finance Ecosystem for Cleantech." *IEEE Transactions on Engineering Management* 70 (3): 1026–1039. https://doi.org/10.1109/TEM.2022.3153319.

Pantea, S., and M. Tkacik. 2024. "Venture Capital and High-Tech Start-Ups in Europe: A Systematic Review of the Empirical Evidence." *Venture Capital: An International Journal of Entrepreneurial Finance*. Advance online publication: https://doi.org/10.1080/13691066.2024.2315069.

Petkova, A. P., A. N. U. Wadhwa, X. I. N. Yao, and S. Jain. 2014. "Reputation and Decision Making Under Ambiguity: A Study of U.S. Venture Capital Firms' Investments in the Emerging Clean Energy Sector." *Academy of Management Journal* 57 (2): 422–448. https://doi.org/10.5465/amj.2011.0651.

Pierrakis, Y., and R. Owen. 2022. "Startup Ventures and Equity Finance: How Do Business Accelerators and Business Angels' [*sic*] Assess the Human Capital of Socio-Environmental Mission Led Entrepreneurs?" *Innovation: Organization and Management* 25 (4): 371–395. https://doi.org/10.1080/14479338.2022.2029706.

Polzin, F. 2017. "Mobilizing Private Finance for Low-Carbon Innovation – a Systematic Review of Barriers and Solutions." *Renewable and Sustainable Energy Reviews* 77:525–535. https://doi.org/10.1016/j.rser.2017.04.007.

Polzin, F., F. Egli, B. Steffen, and T. S. Schmidt. 2019. "How Do Policies Mobilize Private Finance for Renewable Energy?—A Systematic Review with an Investor Perspective." *Applied Energy* 23 (6): 1249–1268. https://doi.org/10.1016/j.apenergy.2018.11.098.

Polzin, F., P. von Flotow, and L. Klerkx. 2016. "Addressing Barriers to Eco-Innovation: Exploring the Finance Mobilisation Functions of Institutional Innovation Intermediaries." *Technological Forecasting & Social Change* 103:34–46. https://doi.org/10.1016/j.techfore.2015.10.001.

Siefkes, M., O. Bjorgum, and R. Sorheim. 2023. "Business Angels Investing in Green Ventures: How Do They Add Value to Their Start-Ups?" *Venture Capital: An International Journal of Entrepreneurial Finance*, Advance online publication: https://doi.org/10.1080/13691066.2023.2260101.

Tranfield, D., D. Denyer, and P. Smart. 2003. "Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review." *British Journal of Management* 14 (3): 207–222. https://doi.org/10.1111/1467-8551.00375.

Uyarra, E., P. Shapira, and A. Harding. 2016. "Low Carbon Innovations and Enterprise Growth in the U.K.: Challenges of a Place-Blind Policy Mix." *Technological Forecasting & Social Change* 103:264–272. https://doi.org/10.1016/j.techfore.2015.10.008.

Vanacker, H., A. A. Lemieux, and S. Bonnier 2022. "Different Dimensions of Durability in the Luxury Fashion Industry: An Analysis Framework to Conduct a Literature Review." *Journal of Cleaner Production* 377: 134179.