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PERSPECTIVE

Financing the energy transition: four insights and avenues for future research

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In line with the Paris Agreement, the European Union (EU) committed to cutting emissions by at least 55% by 2030 compared to 1990. Additionally, the EU committed to reaching climate neutrality by 2050, and, more recently, the energy transition has gained even more urgency with Russia's invasion of Ukraine. Reaching these targets requires massive investments, ranging between US$133 billion and US$266 billion annually until 2050 for the energy sector alone [1]. On the one hand, total energy investment must increase; on the other hand, energy investment must shift from high-carbon to low-carbon technologies. Because of the long lifetimes of energy assets, it is critical that the shift happens now. Finance is particularly important to this transition because we need to be moving from high operational expenditure (OPEX) technologies to high capital expenditure (CAPEX) technologies. Financing conditions and the associated costs of capital (CoC) affect relatively high-CAPEX renewable energy (RE) technologies more than they affect relatively highOPEX fossil fuel–based technologies.

The EU Horizon 2020 program INNOPATHS provides a rich picture of the state of energy finance and the role finance plays in accelerating or hindering the energy transition[8]. We summarize the four key insights from this four-year research project in figure 1. While most of the research featured in this perspective is focused on Europe, insights will also be valuable for other OECD countries.

1. Required capital is available, but the type of capital needs to match demand

The investment needs may seem enormous, but when we compare the available sources of funding for each technology with the funds required to realize the transition scenarios compatible with climate neutrality, we find that two to six times the required capital (up to US$858 billion) is available [1, 2]. However, we find a qualitative mismatch. First, RE production is usually realized in project finance structures, as balance sheets of new players in the industry tend to be small [2]. Institutional investors such as insurers, pension funds, or sovereign wealth funds that manage the bulk of available capital can only partially allocate their funds to such projects due to their restrictive mandates and preference for large investment ticket sizes usually starting at around US$50 million. Consequently, we find a shortage of small-ticket, high-risk funds (in the range of US$50 000 to several million) that enable experimentation on new technologies to bring down their costs through learning-by-doing. Currently, only state investment banks (SIBs) and digital finance platforms are available to fill this gap and accept below market returns or longer payback periods creating a bottleneck in scaling up novel technologies.

Researchers and industry partners need to team up to develop innovative financial products to bundle

[8] To the best of our knowledge, the INNOPATHS finance workstream (see https://innopaths.eu/) has been the largest collaborative research effort on real asset finance in the energy sector in Europe, involving 12 researchers from 5 institutions and publishing 26 papers, reports, and deliverables between 2018 and 2021. The overarching aim of INNOPATHS was to develop multi-model scenarios for deepdecarbonization of the European Economy until 2050. As virtually all scenarios involve high levels of electrification, understanding the financing of these investments constituted a key part of the project.

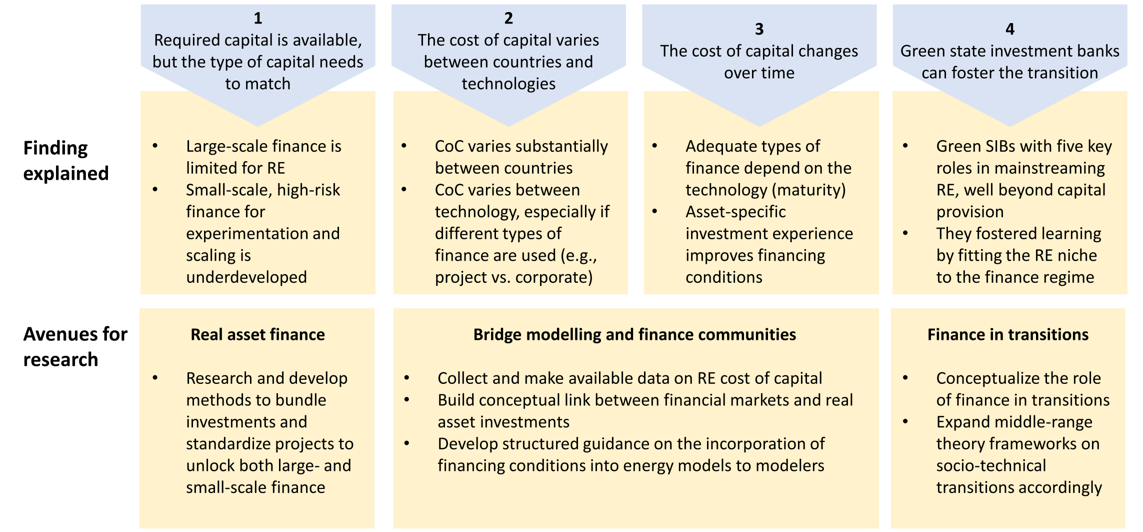

Figure 1. Key findings and avenues for research.

risky projects and smaller tickets into larger funds. Moreover, it is necessary to standardize the climate impact assessment of projects and companies to create green/climate bonds or green yieldcos. Only then can policymakers in finance adjust liquidity requirements and asset risk classifications and reform the prudential regulatory frameworks for pension funds, insurers, and banks (e.g. Solvency II and Basel III) to unlock institutionalized sources of finance.

2. The cost of capital varies between countries and technologies

The CoC varies widely across countries and technologies, with widespread effects on the total cost of different energy technologies [3]. For example, in 2015 the CoC for utility-scale onshore wind and solar photovoltaics projects was estimated at around 3% in Belgium and Germany, while it reached double digits in Greece and Hungary [4]. Data from the same study reveal important differences across conventional and RE technologies, with CoC differing markedly between coal-fired (5.4%–9.5%), gas-fired (1.4%–5.6%) or solar-powered plants (3.2%–12.0%). Similarly, studies have found a cost of debt spread between RE and non-RE firms [5], and more recent survey analyses confirm large spreads between countries and technologies [6]. Notably, country differences are already substantial within the EU and become even more relevant when analyzing global energy transitions, leading to potential investment bottlenecks in developing economies in particular [7].

Incorporating reliable CoC assumptions in energy system models is therefore crucial to providing meaningful results [8]. Until recently, energy system models used uniform CoC [9]. Partly based on findings from INNOPATHS research, IEA and IRENA have now begun updating and differentiating the CoC in their models instead of using uniform rates. Currently, the IEA uses CoC ranges based on a detailed analysis for solar PV in China, Europe, India, and the United States [10, 11]. IRENA uses a technology-neutral CoC of 7.5% for OECD countries and China (falling to 5% in 2020), and 10% for the rest of the world (falling to 7.5% in 2020) [12]. Given these developments, we stand at a turning point. Incorporating finance and more differentiated CoC will likely become the new standard in the energy modelling community. To support rapid and correct implementation, energy finance researchers should begin developing an open-source data repository for CoC, complemented with a guide for modellers on the use of detailed CoC figures and join efforts to endogenize CoC in models to the extent possible. Policymakers in turn are advised to make decisions based on analyses that meaningfully incorporate financing cost differences by countries and technologies. Such analyses are particularly important in the design of the European Green Deal and the corresponding allocation of investments.

3. The cost of capital changes over time

Guiding energy investment decisions typically involves modelling over multiyear or decadal time horizons due to the long asset lifetimes. Hence, getting the current CoC right (section 2) is a first step, but getting the development right over time is also necessary. Our research has shown that the required types of financing vary along the technology lifecycle as the risks these technologies are exposed to evolve [3, 13]. Additionally, investors learn over time to evaluate risks and better assess projects for new technologies, allowing these investors to provide cheaper financing as they gain experience [14]—a dynamic we termed 'financial learning.' While these two factors are technology-specific, the general investment environment also matters. A large share of the financing costs incurred when building new RE assets is due to the general interest rate [14], which varies dynamically over time. If interest rates go up, the cost-competitiveness of high-CAPEX assets deteriorates compared with that of low-CAPEX assets, linking the energy transition to the overall macroeconomic situation and monetary policies [15].

For research, all this means that we need to incorporate technology maturity and financing maturity in models that compare cost-competitiveness between different energy technologies. For longer time horizons, it becomes important to consider scenarios. For example, employing a uniform CoC assumes full convergence over time across countries and technologies. While such a scenario may be instructive, it must be labelled clearly, and policymakers using it to inform decisions must be aware of this assumption [9]. At the same time, policymakers aiming to phase out RE support schemes need to be aware of the effects of rising interest rates and their impact on the cost-competitiveness of renewable projects and the political economy [16]. 'Thermostatic' policies, which automatically adjust support levels to market environments, may be a remedy [15], and policies should generally be designed such that potential changes are well communicated, phased in gradually, and do not apply retroactively [17].

4. Green state investment banks can foster the transition

While mature RE technologies such as onshore wind and solar PV have become a standard asset for mainstream investors, they were a largely nonbankable niche asset two decades ago. To make such novel technologies investable—and thus allow for financial learning (section 3)—SIBs have been an important policy instrument in countries like Germany or the United Kingdom [18]. Our research has shown that green SIBs have historically taken on five distinct roles: (a) capital provision, (b) de-risking, (c) education, (d) signalling, and (e) first mover. SIBs have provided capital in different forms (e.g. grants or loans) to finance new technologies that the market perceived as too risky, and/or de-risked projects through loan guarantees. For example, SIBs in Germany and the UK committed US$126 billion and US$3.2 billion respectively to RE projects between 2012 and 2016 [18]. However, SIBs have also played an important role in educating investors, project developers, and technology providers by providing tools and knowhow for technology risk assessments. Given their in-house capabilities and knowhow, SIBs have taken on a signalling role, and market participants have more confidence in the quality of a project if an SIB invests in it. Finally, SIBs often move first into technologies where private banks require a track record to provide credit. This partially addresses the shortage in early-stage finance mentioned in section 1.

The contributions of SIBs toward the deployment of RE technologies underline the importance of this policy instrument, which should thus be included in the analysis of policy mixes for the energy transition [17]. Moreover, future research concerning specific policy calibrations (e.g. the mandate) and the impact of the political economy on the ambition and effectiveness of SIBs could generate actionable policy insights—for example, to mainstream technologies such as green hydrogen, battery storage, or synthetic fuels. However, setting up such institutions as (revolving) funds that need secure market-rate financial returns to ensure their own continuity hampers their ambition and usefulness in the transition. From a transition theory perspective, much of the SIB activity should be seen as fitting the niche of RE finance to the general finance regime, although it can also help transform the regime through evolutionary processes [19].

5. Avenues for future research

We distill three avenues for future research from our four insights. Section 1 outlines the importance of considering *types* of finance for the energy transition. Mainstream finance research is typically concerned with secondary markets, possibly because of widespread data availability. To provide meaningful insights for the energy transition, however, data and research on smaller tickets and riskier, nontraded equity-type assets would complete our understanding of where finance may cause bottlenecks in the transition. Moreover, as financial asset markets are interconnected, exploring how the availability of funds in different asset types (fails to) match the dynamics of demand is important to build better finance modules into energy system models and integrated assessment models that inform policymakers.

Sections 2 and 3 demonstrated the heterogeneity and the dynamics of the CoC for RE. First, researchers must broadly and regularly gather and make available data on RE financing conditions. IRENA and IEA/WEF have both launched projects to collect such data, which should be made publicly available. To some degree this also holds for conventional power where more data is available due to the balance sheet financing but differing financing costs are still seldom considered. Second, researchers need to build the conceptual links between financial markets and the real asset CoC. Technological maturity, financial market structure, and the available types of finance will co-determine the cost of capital for different assets. Third, modelers need guidance on how to operationalize the empirical dynamics. Such guidance should be developed in cross-disciplinary teams to ensure the empirical accuracy of the models and their usefulness for policymakers.

Finally, section 4 points toward the important role of finance in socio-technical transitions, with the direct market activity of state organizations being an often considered and potentially effective policy intervention. While INNOPATHS research mainly focused on RE finance, a more general understanding of finance in transitions would allow effective policy interventions to be designed for less mature low-carbon technologies in other sectors. We believe that using middle-range transition frameworks such as the Technology Innovation System or the Multi-Level Perspective are promising approaches to that end, deepening the understanding not only of SIBs but also, more generally, of actors at the intersection of energy and finance [20].

Data availability statement

No new data were created or analysed in this study.

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Conflict of interest

The authors declare no competing interests.

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