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How to fill the ‘financing gap’ for the transition to low-carbon energy in Europe?

Friedemann Polzin
Mark Sanders

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U.S.E. Research Institute
Kriekenpitplein 21-22, 3584 EC Utrecht, The
Netherlands Tel: +31 30 253 9800, e-mail:
use.ri@uu.nl www.uu.nl/use/research

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Friedemann Polzin
Mark Sanders

Utrecht School of Economics
Utrecht University
Sustainable Finance Lab
Utrecht University

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Abstract
In models exploring energy transition pathways, existing investment flows are contrasted with predictions for investments needs to indicate a 'financing-gap' for the European energy transition. The authors draw on an in-depth analysis and comparison of the main scenarios being employed to forecast investments until 2050 as well as an analysis of the literature on the sources of finance for renewable energy. Long-term projections do not capture the supply or demand of specific sources of finance needed to cover the whole innovation chain. Our analysis reveals that under the individual investment and lending criteria/mandates the money is available. However, policy uncertainty strongly distorts investment decision making. Especially institutional investors and lenders such as pension funds and banks shy away from investments in the energy transition because of expected (policy) discontinuities and the risk of stranded assets. Moreover, more risk-bearing equity capital to finance the early stages of innovative clean energy technologies is needed to complement existing large-scale investments in existing technologies to allow for an effective and efficient mitigation that is in line with the major scenarios. Based on the analysis we develop a matrix that indicates the role for different sources of finance and new intermediation channels in the energy transition and how they need to be engaged..

Keywords: Clean energy investments, mitigation pathways, sources of finance, financial system, empirical review

JEL classification: : G23, G24, G28, O31, Q28

Comments welcomed to: f.h.j.polzin@uu.nl

1 Introduction

'The business case of sustainability is challenging, particularly in the short term, but on the middle and long term, this is the way to go. […] We should support this effort… for the Earth' (Thomas Buberl CEO AXA, keynote at the Climate Finance Day 2018).

In order to reach the targets set out by the Paris agreement in 2015, recently re-coined as 'carbon law', a significant reduction of CO2 emissions is necessary [1]. Recent evidence, based on a simulation of energy supply and demand in 139 countries, demonstrates that 100% renewable energy system is achievable in 2050 [2]. This would require political commitment and innovative scalable technological solutions that allow reconciling economic development and emission reduction. Numerous scenarios and models exist that analyse possible pathways towards this goal, with prominent studies coming from IEA/IRENA (WEM) [3,4][1], PRIMES [5,6][2], LIMITS/CD-Links integrated assessment models (IAMs)[3] and Shared Socio-economic Pathways [7,8].

Many studies highlight the large amounts of investment into energy supply and demand that is required. These cover both established mature technologies as well as innovative technologies [9–14] and can be summarized under the header of 'moving the trillions' [15]. Rough global estimates range from 53 USDtn to 90 USDtn until 2050 – including infrastructure [16,17]. Scholars document model and scenario-based [11,18] as well as empirical evidence [19–21] of a financing gap for renewable energy and the energy transition more broadly.

We contribute to the literature by addressing an emerging debate on the sources of finance [19,22,23]. McCollum et al. [18] already asserted that '*what this mix of investments should look like is very much an open question, however, especially at the national and regional level*'. But also in the authors' follow-up study in 2018 this question remains largely unaddressed [11]. Private financing has been shown to play an important role. For example some 90% of RE projects were being financed privately in 2017 [24]. In this paper we address what types of finance can finance what type of investments and as such we build on the stream of literature that focuses on investment risks and return [25–27] as main determinants of investor behaviour.

How much private finance is (roughly) needed for a low-carbon energy transition in Europe until 2050 but more importantly: in what mix should it be(come) available?

To answer the RQ, this article first systematically summarizes recent model and empirical based evidence on the available transition paths and the corresponding investment

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[1] http://www.iea.org/weo/weomodel/

[2] https://ec.europa.eu/energy/en/data-analysis/energy-modelling

[3] http://www.feem-project.net/limits/ and http://www.cd-links.org/

demands. We then show there is a lack of private small-scale equity investment to promote RD&D and low risk but small ticket financing investments for RE projects. Large scale, low risk debt investments are not yet suitable for renewable energy projects mainly because of regulatory barriers. New forms of intermediation and a set of enabling reforms (mainly addressing regulatory issues and standards) could help unlocking under-utilized sources and facilitate the energy transition in Europe.

The remainder of this paper is structured as follows: Section 2 describes the methodology used to review empirical and model-based evidence as well as literature. Section 3 lines out the demand of finance put forward across different scenarios where section 4 reviews potential and suitability of different sources of finance. Section 5 discusses the major findings and develops a matrix for engaging private investors whereas section 6 derives specific implications for policy and financiers.

2 Methodology

We build on methodology deployed by Blyth et al. [19] referred to as 'systematic narrative synthesis' [28]. First, we collect existing 'narratives' about European energy investment needs, using historical data and existing scenarios for future investments. Second, we link or 'synthesize' the demand for finance and supply of power using the evolving structure of the power supply system and corresponding investment demand by technology life cycle stage. We then disentangle via a historical analysis different financing sources for investments in different lifecycle stages [22] and contrast these with future investment needs.

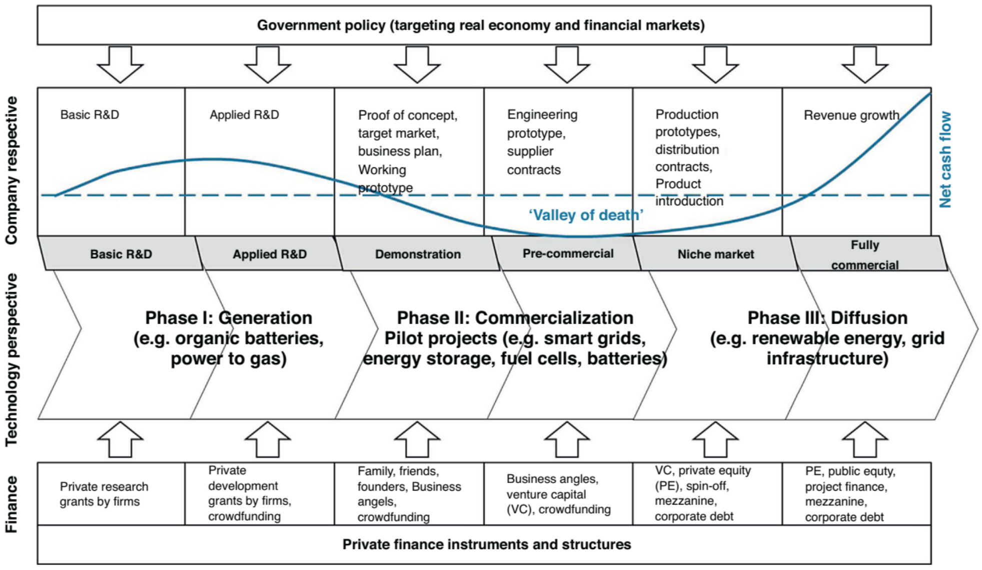
The most widely used and cited models generating energy sector scenarios and projections serve as a starting point of our scenario analysis: IEA WEM [4,29], PRIMES (Winter package) and EU reference scenario [6] and output of the LIMITS [18,30] and CD-Links projects [11]. To reduce complexity, we focus on models/scenarios that include renewable energy (RE) investments and/or capacity. We then collected key data such as quantified investment needs, existing capacity, cumulative new build and retired capacity, capital costs. The outputs of the scenarios come in many different forms: Energy (PJ/EJ/TWh), capacity (GW) or monetary. The period covered was 2000-2050 in 5-year spans. Most of the data is only available on an aggregated level (Europe/EU/global) and for certain rough technology categories i.e. Wind (onshore, offshore), Solar PV and Biomass. To complete the picture in many models demand side investments are indirectly taken into account. For example the LIMITS models assume that 'the investments made to reduce energy demand could be equated to the investments that have been simultaneously offset on the energy supply side' [18].

3 Dynamics of the 'financing gap' for low-carbon energy

3.1 Determinants of financing low-carbon energy

According to the efficient market hypothesis and the Modigliani-Miller Theorem [31], capital availability can be treated as given and comes in the required form, as long as financial market actors possess enough information on the projects under consideration. Money is seen as a commodity. These are the assumptions that underlie many Integrated Assessment Model (IAM), Computable General Equilibrium models (CGE). In a second set of models, non-equilibrium/demand-led based on Post-Schumpeterian and Post-Keynesian thoughts, money is treated as an asset and credit is being created based on expectations about future profits of an innovation. For a detailed discussion on the representation of the financial sector, see Mercure et al. [32]. However, under the so-called adaptive market hypothesis [16,33], the behaviour of investors plays an important role in the (uncertain) energy transition. Hence even if the main climate externality was addressed by a global CO2 cap and trade systems financing gaps would still persists as there are more market failures related to characteristics of the different types of finance [12].

An innovation-led sustainability transition requires both investments in invention and innovation as well as diffusion [12,34,35]. In the literature typically researchers ignore the importance of the changing nature of financing needs over the life cycle and simply aggregate the funding gap over all sources. The framework developed by Polzin et al. [13] provides some direction from both the company and technology perspectives (see Figure 1). In the beginning of the technology lifecycle it assumes public R&D investments that lead to a positive cash flow of the company developing the respective technology. The demonstration pre-commercial and niche-market phase are the most problematic where cash-flows are negative. Only when reaching the fully-commercial phase this company is expected to be profitable.



Current Opinion in Environmental Sustainability

Figure 1: Financing energy technology innovation and entrepreneurship (Source: Polzin et al. [13])

On the technology level the framework proposes to distinguish clearly between early stages in the technology lifecycle (innovation/upstream) and later stages (diffusion/deployment/downstream). In addition, Figure 1 shows that different sources of finance are being used as projects have different risk/return profiles and these need to match different investors' expectations, sentiments and decision making. For example in the early stages high uncertainty and the presence of knowledge spillovers warrant public intervention such as RD&D support [36,37]. In the diffusion phase financiers are concerned with the risk of stranded assets [38].

3.2 Renewable energy investment needs for Europe

Paraphrasing the 'emissions gap' [39] many scientific studies and reports refer to 'financing gap' when it comes to the energy transition and/or renewable energy capacity [14,20,e.g. 40,41]. The 'financing gap' studies mainly estimate the difference between historical investments and/or committed investments and investments needed to achieve a substantial decarbonisation of the economy.

Table 1: Financing gap across different studies

Study	New policies/ NDC (annual investments) USDbn	2° comp. (450ppm) (annual investments) USDbn	Time	Model	Focus	Technological change	Financial market	Policy	Sources
IEA WEO/ WEIO	54	69	2016-2035	WEM	Bioenergy, Hydro, Wind (onshore + offshore) Solar PV, Other	Learning curves	Capital costs	Energy and climate-related policies (IEA policies and measures database)	[29,41].
LIMITS	29	66	2010-2050	6 IAMs	Renewable energy, nuclear energy and energy efficiency	Knowledge in production functions, learning curves, spillovers	Investment determined by savings, relative prices	Regulation/ standards, externality pricing; subsidies, capacity building	[18]
CD-Links	69	75	2015-2050	6 IAMs	Electricity—non-biomass renewables	Knowledge in production functions, learning curves, spillovers	Investment determined by savings, relative prices	Regulation/ standards, externality pricing; subsidies, capacity building	[11]
CEPA	42	59	2016-2050	PRIMES (CGE)	Renewable energy	Knowledge in production functions, learning curves, spillovers	Interest rates, public finance, taxes	Various policy instruments including ETS	[42]
EU Ref2016	160	-	2016-2050	PRIMES (CGE)	Power plants in general (including fossil-fuel based)	Knowledge in production functions, learning curves, spillovers	Interest rates, public finance, taxes	Various policy instruments including ETS	[5]
European Energy Industry Investments	55	71	2021-2050	Various	Renewable energy	Assumptions regarding economic, technical and market developments and specific investment costs of the respective studies			[43]
Mapping the Gap: The road from Paris (OECD)	85	148	2015-2040	BNEF/ CERES	Clean energy	None	Sources of finance (equity/debt)	Incentives for investors	[44]

Notes: International Energy Agency (IEA), World Energy Outlook (WEO), World Energy Investment Outlook (WEIO), PRIMES integrated assessment model, Bloomberg New Energy Finance (BNEF), National determined contributions (NDC), World Energy Model (WEM), Integrated Assessment Model (IAM), Computable General Equilibrium models (CGE)

Table 1 shows a wide range of estimates, produced by scientific researchers and organisations. We compare investment requirements under a scenario that takes current pledges of national government into account with scenarios that are enable staying below 2°C global warming. Considering only renewable energy power investments, we note that the estimates fall roughly in the same order of magnitude 29-69 USDbn/year (NDC) vs. 54-75 USDbn/year (2° compatible). To better understand the dynamics behind these we disentangle these numbers for R&D and deployment of the major technologies.

3.2.1 Energy supply R&D investment needs (upstream/innovation)

Existing clean energy technologies need to improve their cost-effectiveness and introduce new technological solutions. For this process to happen, technological learning is necessary [12,45,46]. Prior research has established learning curves in various technological development and diffusion processes that form the basis for predicting future technological pathways [47]. Countries around the world are pursuing different strategies to address energy innovation [48].

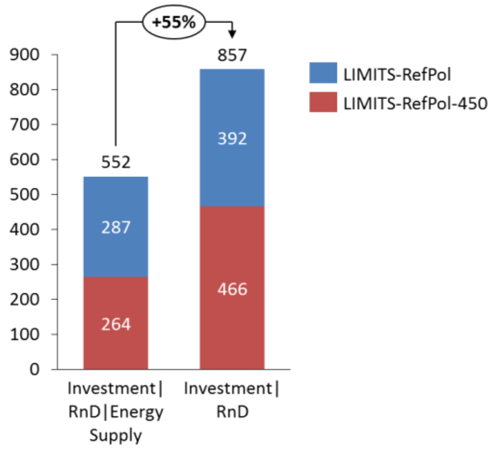


Figure 2: R&D investments in energy supply and total (2010-2050) USDbn (2005 USD) Source: LIMITS

Research from LIMITS project (scenarios RefPol and RefPol-450) reveals the R&D investment needs in Europe until 2050 (Figure 2). Reaching a 2° compatible path would require even less R&D spending in energy supply technologies than in a reference policy scenario (264 USDbn instead of 287 USDbn). However, when looking at the overall energy R&D investment needs it becomes clear that much bigger efforts on the demand side (energy efficiency) are required (392 USDbn increase to 466 USDbn).

3.2.2 Wind, solar and biomass investment needs (downstream/diffusion)

When comparing the investment needs across the different reference and 2° compatible scenarios, a wide range becomes visible. Wind energy investment needs range from 566 USDbn to 1897 USDbn according to research from IEA, CD-Links and EU energy modelling. The REMIND model also features the most rapid upscaling of renewable energy technologies [11]. Other models assume much higher investments into demand-side reduction.

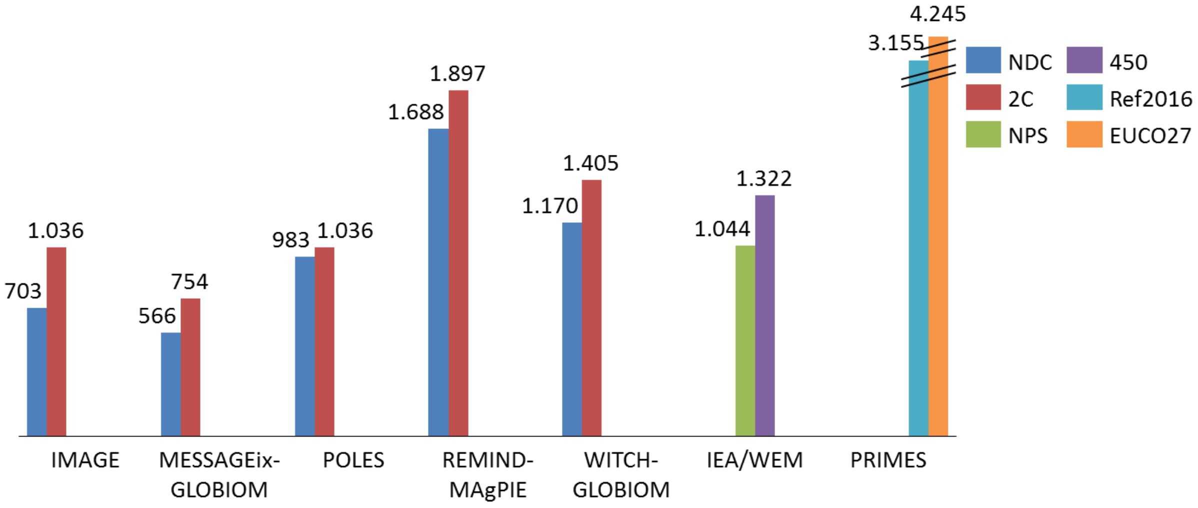


Figure 3: Wind Onshore and offshore investment needs (EU) CD-Links, WEM, PRIMES (2016-2050); Note: Ref2016 and EUCO27 scenarios show total supply-side investment; National determined contributions (NDC) and New Policies Scenario (NPS) represent currently committed investments; 2C and 450 respectively represent scenarios compatible with a two degree world; Ref2016 represents the reference scenarios (PRIMES) and EUO27 scenarios with a focus on energy efficiency. PRIMES: EURbn, IEA/others: USDbn

The investments needs in solar PV technologies vary more across the different models than the investments needs in wind energy capacity. They range from 280 USDbn to 2785 USDbn [11]. Here the balancing of supply-side investments in the more aggressive 2° compatible scenarios is even more visible. Another important finding is that IEA/WEM are at the low-end of the spectrum, potentially underestimating the potential of solar PV [49,50].

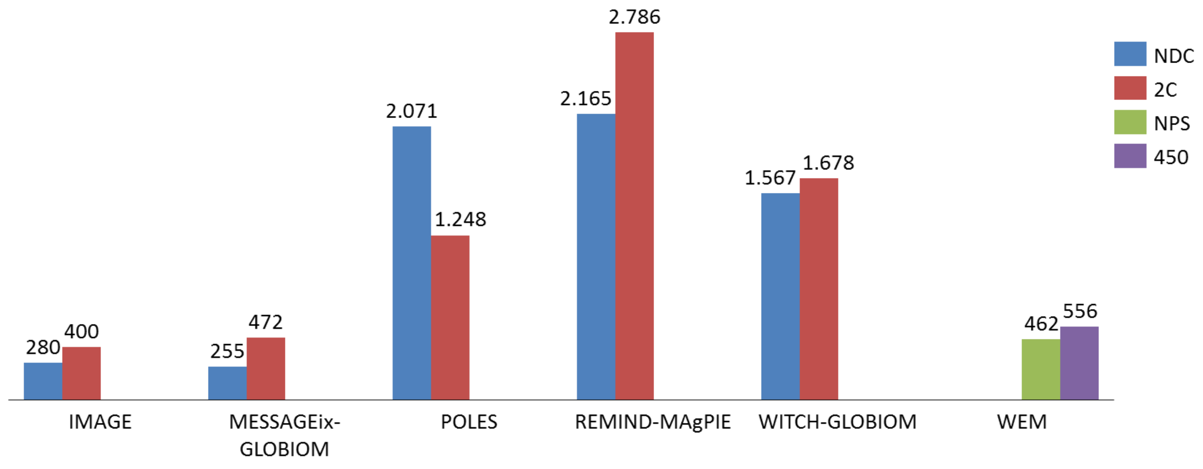


Figure 4: Solar PV investment needs (EU) CD-Links, WEM, PRIMES (2016-2050); National determined contributions (NDC) and New Policies Scenario (NPS) represent currently committed investments; 2C and 450 respectively represent scenarios compatible with a two degree world; USDbn

One pillar of a future low-carbon energy system relies on biomass [51]. Interestingly model predictions vary dramatically when it comes to its future role. Whereas a group of models (IMAGE, POLES; WITCH) predicts significant investments 85-569 USDbn, others do not see any investment flows (MESSAGE/REMIND) [11]. The world energy model predicts moderate investments (324 USDbn until 2050).

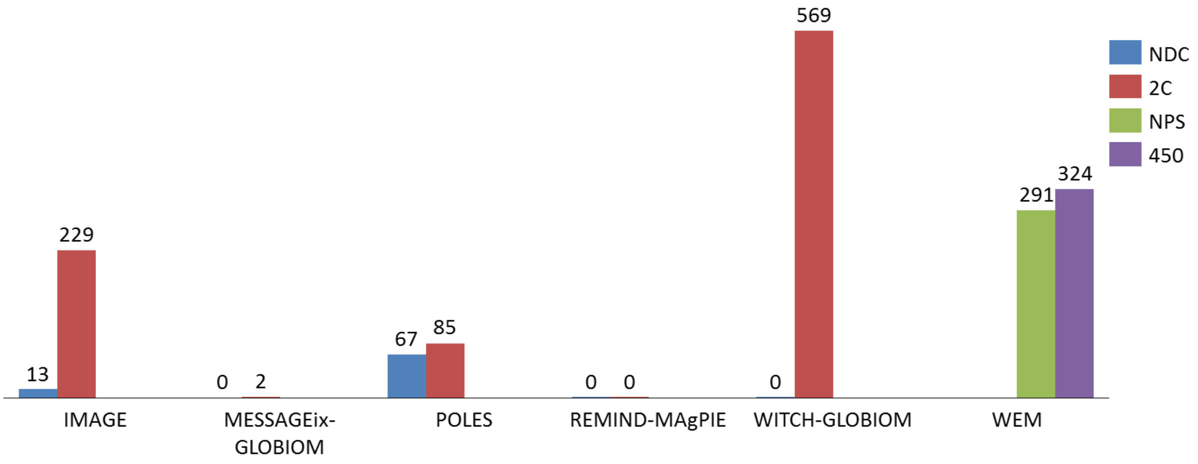


Figure 5: Biomass (with CCS) investment needs (EU) CD-Links, WEM, PRIMES (2016-2050)

3.2.3 Energy efficiency investment needs (downstream)

Scholars and practioners also largely agree that for an efficient energy transitions, major investments have to go into end-use energy demand sectors [4,e.g. 52,53]. However model results in the two main scenarios diverge (see Figure 6).

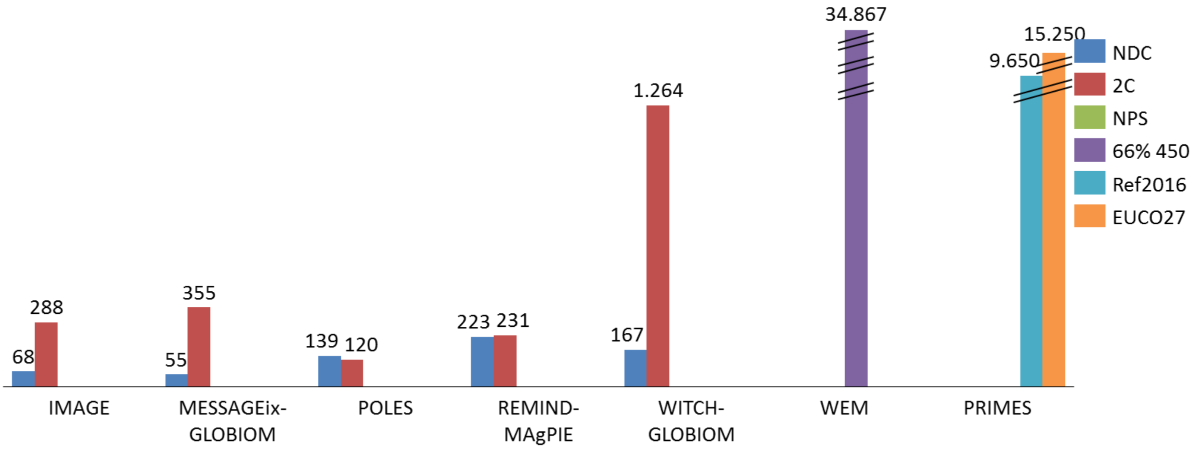


Figure 6:Energy efficiency (demand-side) investment needs (EU) CD-Links, WEM, PRIMES (2016-2050); Note: WEM covers G20 countries; PRIMES numbers include household investments

The IMAGE, MESSAGE and WITCH models predict the highest investment needs of up to 1264 USDbn until 2050. The scenarios from MESSAGEix-GLOBIOM, POLES, and IRENA models show moderate increases in supply-side investments and somewhat more significant increases in total investments when moving from the 'REfPol/NDC' to 2° compatible scenarios. The winter package model (including household investments) predict even 15.250 USDbn. Capros et al. [5] assert that 'large part of total energy-related investment has to take place in the demand sectors, mostly by individuals. The financing of these investment and the removal of barriers appears to be the major implementation challenge'.

4 Sources of finance for the low-carbon energy transition 2016-2050

Many of the scenario-based analyses shown above explicitly or implicitly neglect the sources of finance rather focusing on aggregate investment needs usually expressed in USD. For example McCollum et al. [11] state that *'[…]given the nature of these models, we expressly address the question of 'Where are the investment needs?', not 'Who pays for them?''.* Few studies and organisations hence comprehensively assess (potential) sources of finance for the low-carbon energy transition, although their importance is widely acknowledged [4,12,e.g. 54]. Notable exceptions are Bloomberg New Energy Finance (Trends in RE investments 2009-2018) and a report by the Climate Policy Initiative (CPI) and IRENA [24].

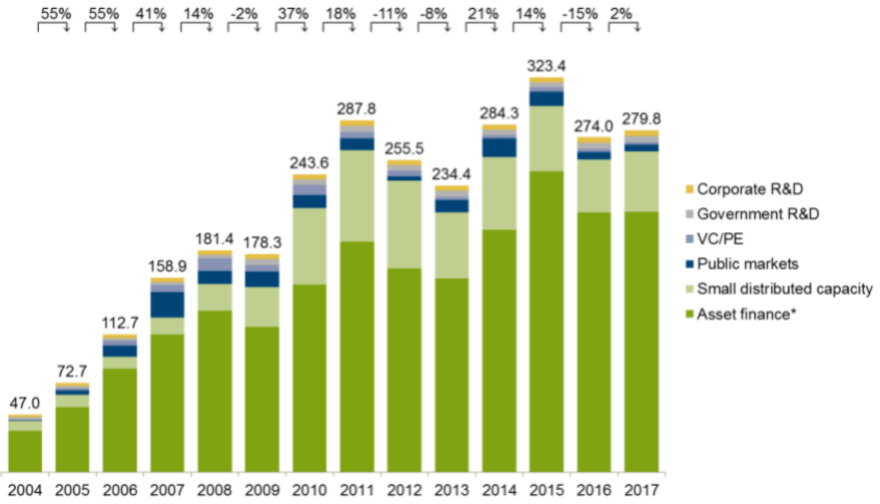


Figure 7: Sources of finance for RE 2004-2017 (Source: [55]) Research and development (R&D); Venture capital/ private equity (VC/PE)

When looking at the financing landscape for low-carbon (RE) technologies, one has to distinguish between upstream and downstream finance (see Figure 1). Most of the global investment volume, that has been rising from 47 USDbn in 2004 to its peak of 323 USDbn in 2013, comes from asset finance (essentially project finance), followed by small- and distributed capacity (mostly household installations). Upstream finance (for R&D and demonstration) as well as risk capital play a minor role quantitatively, but are qualitatively more important in developing the technology. Below we discuss role, volumes, major barriers and solutions for each source of clean energy finance.

4.1 Corporate and government RD&D finance

Innovation in clean energy needs investments into research, development and demonstration (RD&D) [12,56,57]. This assumption is also made in the IAMs scenarios for future energy investments [11,58] as these investments reduce technology costs of the options available. In principle, the funding can come from two sources: Public R&D investments and demonstration projects as well as private R&D investments. Data compiled by the IEA shows that over a period of three years (2014-2017) 1,48 USDbn of RD&D finance has been made available for clean energy, whereas over 5,8 USDbn have been spent on energy RD&D (see Table 2).

Hannon and Skea [56] argue that private entities invest sub-optimally in clean energy R&D, leaving a financing gap. As these technologies have a high probability of failing to reach the market public grants or procurement contracts should finance most of pre-deployment activities [56,59,60]. Research in both energy-supply and energy efficiency has been supported by public authorities; however support for energy efficiency research was often marginalised in favour of supply-side research [56].

One central policy model for supporting innovation has been public investments in basic research, assuming a trickling down of new knowledge generated by research organisations to market participants [61]. The need for more basic R&D and research infrastructure is seen as a 'no-regret' strategy for policy makers. However, it is expected to have little direct impact on entrepreneurs' and investors' decisions to engage in the clean energy sector [23].

Earlier work [57] assessed under which conditions instruments such as public loans, equity investments, prizes and tax credits or rebates can efficiently and effectively support clean energy innovation processes. First, public loans to small firms and start-ups might not appropriate because of their limited ability to pay them back. Second, tax credits prove also to be unfruitful given the low profits of small innovating firms. Third, public equity investments can provide a solution in which the government shares in the upside of the R&D support, when expected net-profits are positive. These investments could also signal quality to private investors [62,63]. If the expected net private revenues of an innovation are negative, prizes or input-driven subsidies (grants or contracts) would be a suitable public funding option [57].

Haley and Schuler [61] analysed the support system for the solar PV industry. They echo other scholars‛ recommendation for a combination of production and consumption support (technology push and demand-pull), e.g. production subsidies, technology transfer, publicly funded R&D alongside feed-in tariffs, renewable portfolio standards, tax credits, and concessionary financing. In addition, the authors highlight the positive experience with the Small Business Innovation Research Program (SBIR). This cost-effective model successfully encourages technological commercialization without creating significant technological bias [61].

4.2 Small- and distributed finance

Increasing diversity in financial systems that beneficial for energy investments and stability of the financial system requires small scale financial sources [13]. Small- and distributed finance (especially crowdfunding/crowdinvesting) can play a significant role in a more decentralized energy transition, as this is most likely to require smaller, non-standardized projects that do not fit mainstream investors categories. Equity and debt crowdfunding has experienced rapid growth in the last 4-5 years, mainly due to technological advancement and regulatory innovation. Volumes increased from 1.2 USDbn in 2013 to 8.1 USDbn in 2016 [64] (see also Table 2). Peer-to-business lending, equity- and reward-based crowdfunding as well as real estate crowdfunding have the most relevance for investments in renewable energy – both upstream (for innovative start-ups) and downstream (citizens as cooperative RE projects) [65].

Nigam et al. [66] empirically investigate the leading 30 crowdfunding platforms specific to renewable energy from seven countries (United Kingdom, United States, Germany, Netherlands, France, Switzerland and Portugal). They show that renewable energy crowdfunding platforms have raised a combined total of almost 305 EURm, of which the lending-based model has contributed the most [66]. For example, Windcentrale, the largest crowdfunding initiative in the Netherlands, attracted more than 15 USDmn in equity investments [65].

Engaging citizens in this way reduces perceived risks of RE and has the potential to democratize the energy transition. Also these models mobilize resources from heterogeneous groups, ranging from financial investor to non-traditional small-scale investors such as farmers’ and other individuals [65]. However, for small- and distributed finance to work scholars agree that policy instruments such as feed-in tariffs, quota-based schemes, tax incentives or grants are critical [67]. In Japan, the Hometown Investment Trust (HIT) funds are a new source of financing to support solar and wind power. HIT funds connect local investors with projects in their geographical proximity, where they have personal knowledge and interests. Wind power and solar power projects could thus raise money from individuals (about 100 USD–5000 USD per investor) interested in promoting clean energy [68]. By linking investors to projects at the local level, these platforms also reintroduce a more direct connection and responsibility.

4.3 Venture capital and private equity

Venture capitalists (VCs) provide entrepreneurs with funding between R&D phase and commercialisation [69]. Venture capital funds are regularly structured as 10-year partnerships, where outside investors (the limited partners) provide capital to the VC fund (run by the general partners) to make high-risk, high-reward investments, typically consisting of a portfolio of 10–20 startups [70]. They can hence play a critical role in bridging the 'valley of death' (see Figure 1) that new companies face when their technology is too advanced to receive public research support but not yet technically or commercially mature [71]. Clean energy ventures exhibit specific characteristics that limit their access to capital such as greater technological uncertainty, higher policy risk, capital intensity and asset heaviness, slower scalability, and corresponding long payback periods [71,72].

From 2007-2015 investments in cleantech (renewable energy) in Europe totalled 23.20 USDbn (EVCA, 2015), which compared to all high-tech investments (41.47 USDbn) represents a good engagement. However, overall VC investments in the same period amounted to 423.17 USDbn (see Table 2), more than tenfold the high-tech investments.

Despite the promises of this type of investors in driving the cleantech revolution/transition, scholars have increasingly taken a critical stance: VC investments are moving away from radical technologies related to energy production ('deep technology' investments such as new hardware, materials, chemistry, or manufacturing processes) and increasingly focus on energy efficiency, software, energy-storage and transportation characterised by high technology risk, but low capital intensity [70,73]. This is related to the high capital expenditure (CAPEX) for emerging ventures and technologies that must compete in the merit-order with the (low) variable cost of continuing operation of existing plants. Examples include offshore wind farms, advanced biofuel refineries and the first commercial plants for unproven solar cell technologies [35].

To better judge the potential of VC investments, three interdependent characteristics of markets—growth, scalability, and rapid payoffs—are important [74]. Many technologies such as grid infrastructure, solar facility installations or biofuels not readily suit the VC business model. Investors would need to lengthen the time horizon of involvement in investments—that is, more investment and involvement in firms at an early and later stages and essentially 'move out of their comfort zone' [69]. The interdependence of the infrastructure and clean technologies (e.g. electric vehicles and charging stations) adds risk to investments that VC-investors cannot manage. Hence VC investors make many small investments in a large number of less mature companies to hedge against this risk [69].

Previous research also reveals interdependencies between VC and institutional investors. Migendt et al. [71] show that the previous level of investments of institutional investors into VC/ PE and the presence of local anchor investors significantly shape renewable energy industry emergence and growth. When regulation thinned out the European investor base, VC/PE investors experienced difficulties in fundraising for VC/PE and thus capital constraints [71]. Schock et al. [75] find that capacity investment is driven by technology investment (VC/PE) whereas in the reverse, they do not find evidence for a stimulus to technology investment caused by an increase in capacity investment.

To address barriers to successful VC engagement in clean energy, scholars analysed a menu of policy options. Both supply side policies (university R&D support, SBIR grants) and deployment policies (feed-in tariffs (FITs), regulations and standards, designed with a long-term perspective of creating a market for environmental technologies, are associated with higher levels of venture capital relative to more short-term fiscal policies [23,76]. Also certain (de)regulatory actions, large-scale demonstration projects, and/or procurement decisions can encourage entrepreneurial activity and corresponding VC investments [74]. In contrast, large loan guarantees are unlikely to be effective for small scale ventures [74]. Policy makers may also change the framework conditions for early-stage VC/PE investments in general. Increasing the functioning of equity capital markets will allow investors to sell the companies they have grown through an initial public offering (IPO). Other framework conditions include most notably the tax regime that encourages risky early-stage investments. Also an entrepreneur-friendly bankruptcy legislation and exit possibilities would encourage more potential entrepreneurs to enter the highly uncertain clean energy tech sector [23,72].

4.4 Bank finance (debt)

Banks are one of the major sources of finance both for SMEs/companies (corporate debt on-balance sheet financing) as well as project finance [77]. From 2002 to 2010 corporate lending to companies operating in the renewable energy sphere in Europe totalled around 33 USDbn with a potential of more than half a trillion Euros, currently outstanding loans to non-financial corporations (Table 2). Zindler and Locklin [44] assert that to date, the vast majority of clean energy power generation debt has been financed through direct loans from project financiers, such as major banks.

There are two main barriers relating to a large-scale deployment of bank finance for clean energy: First, after the global financial crises banks saw a period of lack of confidence and decreased economic activity combined with increased regulation and compliance which led to lower overall levels of lending [13,40]. Unintended consequences of Basel III financial regulations constrain banks to finance long-term infrastructure projects. Work by OECD [78,79] shows that Basel III may have unintentionally constrained the ability of banks to provide long-term debt financing to capital-intensive renewable power infrastructure projects. Campiglio [40] discusses the relevance and feasibility of using macro-prudential financial regulation to expand the amount of credit flowing to low-carbon activities, assigning lower risk weights to ‘green’ loans vs. ‘brown loans’ (the introduction of differentiated reserve ratio requirement), relaxing liquidity rules and matching long-term loans with similarly long-term liabilities. Others have argued strongly against such ‘green’ support factor and instead argue that ‘brown’ projects should carry an additional risk premium to capture the policy and environmental risks involved [80]. More radical proposals include binding debt extension to RE investment itself, which could provide a self-regulating incentive to the financial system to actively pursue the energy transition as financial commitments of future consumption (debt) would be limited by future energy availability [81].

The second factor limiting green investments is their unattractive risk/return profile. Many banks are constrained in their ability or interest in extending long-term loans due to the relatively short maturity on the liability side of their balance sheets. However, many clean energy projects (including energy efficient buildings) are long-term in nature. Banks are currently ill-equipped to assess environmental and technology risks. The lack of borrowers’ environmental information (e.g., a borrowers’ emissions data and technologies employed) limits banks’ ability to assess the environmental risks involved in project and corporate finance [40,82]. The relative immaturity of the clean energy industry increases the perception of risks related to technology evolution and market development. In this respect banks lack analytical and implementation capacity or judgement to assess these highly complex and evolving risks [82]. Most importantly, clean energy investments are perceived as being dependent on public support, which has not been as transparent and predictable as banks would like to see it. In some cases, this has gone so far as to introduce retroactive adjustments producing strong credibility issues for years to come [40]. Other scholars point out banks suitability in financing energy efficiency applications such as retrofitting homes and office spaces with more energy efficient materials, since these businesses do not face technology risk [73]. The problem here is that the tickets are very small as such investments are made project by project and building by building.

Assigning a carbon price and/or introducing a cap-and-trade system globally which banks can observe and integrate into their risks models proves difficult. Country authorities could consider initiatives to promote coordinated domestic responses for clean energy finance in the banking sector, in consultation with key stakeholders such as banking associations, banking regulators, relevant ministries, securities exchanges, and credit bureaus exemplified by the Dutch ‘Energieakkoord’ [82]. Another practice is exemplified by the US Department of Energy (DOE) ‘Loan Program’ which aimed at scaling up domestic innovative and mature clean energy technologies [74].

From within the sector key initiative include the equator principles or integration of ESG criteria into banking operations; for example the Global Alliance for Banking on Values (GABV), the Network Greening the Financial System (NGFS), UNEP Inquiry or the 'Alliance of Energy Efficiency Financing institutions', with a new focus on funding residential and industrial energy efficiency. These learning networks for capacity building should be extended [82].

4.5 Institutional investors (Public and private equity)

Institutional investors such as sovereign wealth funds, pension funds and insurance company but also endowed foundations and family offices are among the largest sources of capital available in today's financial markets [83] with total assets under management (AUM) of 27 USDtn in the OECD countries [79,84]. However, their engagement in RE finance to date has been limited – 2,3 USDbn globally (IEA/IRENA 2018), which has partially been attributed to strong path dependency for these institutional investors. Figure 8 shows the investment volumes in sustainable energy projects of institutional investors through their major investment vehicles.

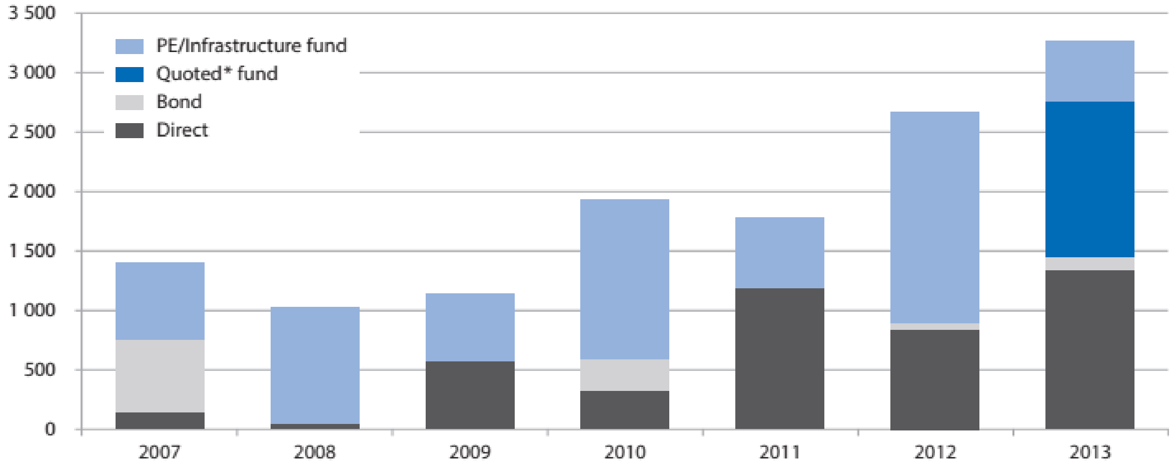


Figure 8: Institutional investor commitment to European sustainable energy projects in USDmn Source: [85]

Many of the studies exploring the barriers to more extensive engagement of institutional investors have focused on the *problems* with government support for infrastructure projects, lack of investor capabilities (principles and skills) and problems with investment conditions (the projects themselves) [82,84]. In addition, scholars and industry organisations have identified political, policy, regulatory risks, commercial and technical risks as well as market risks [83,84]. Longevity risk (i.e. long-term performance) is perceived to have the highest probability and severity ('tragedy of the horizons') as energy systems will be built around new technologies (such as wind and solar). Investors are concerned with the apparent mismatch between the long-term nature of capital commitments inherent in clean energy financing and the relatively short time frame of regulations according to a study of OECD institutional investors [84]. Illegitimate policy and regulatory changes pose a real threat to clean energy financing (see also above for bank finance). Eeconomic/commodity price volatility (i.e. future electricity prices) is considered a highly probable and severe risk [79].

4.5.1 Sovereign wealth funds

Sovereign Wealth Funds (SWF) combine a long-term investment often with specific socially responsible investment (SRI) objectives though mandates to address significant public policy issues that could affect intergenerational aspects of sustainability [86]. Examples include the Norwegian SWF fund with AUM more than 1 USDtn. According to the SWF Institute green growth investments are increasingly becoming a focus for SWF funds [87]. In Europe SWFs could provide more than 1300 USDbn as investments (see Table 2).

Table 2: Overview volumes sources of finance for EU/Europe

Source	Lower bound (USDbn)	Upper bound (USDbn)	Sources	Remark
RD&D finance	1,48 (2014-2017)	5,8 (2014-2017)	IEA (2018)	Upstream
Small- and distributed finance	0,33 (2014-2017)	8,11 (2014-2017)	(Nigam et al., 2018) (Ziegler et al., 2018)	Upstream and downstream
VC and private equity	23,20 (2007-2015)	41,47 (high-tech 2007-2015) 423,17 (2007-2015)	ECVA (2015)	Upstream and downstream
Bank finance (debt)	33,38 (2002-2012)	608,40 (2018)	BNEF (2013) ECB (2018)	Downstream
Sovereign wealth funds	12,35 (2007-2013)	1310 (2018)	Preqin (2018)	Downstream
Pension funds		1581,04 (2018)	EFAMA (2018) (OECD, 2015a)	Downstream (indirectly upstream through VC)
Insurers		1411,64 (2018)	EFAMA (2018)	Downstream
State investment banks	78,02 (2018)	240,44 (2018)	Mazzucato & Semieuk (2018)	(Upstream and) Downstream
Green/ climate bonds	509 (2014-2018)	11024,24 (2018)	Climate Bonds Initiative (2018) EFAMA (2018)	Downstream
Public equity	26,56 (2002-2012)	9588,70 (2018)	(Frankfurt School-UNEP Centre/BNEF, 2018) FESE (2018)	Downstream

Notes: Lower bound: investment volumes in RE/clean energy currently (latest available source) realised from this source; Upper bound: maximum potential from this source (current market volume/assets under management or general investments from this

source in period indicated) given restrictions of their mandates (more details on calculation in Table A.1 in the appendix)

4.5.2 Pension funds

Pension funds (most of them defined contribution) represent one of the major sources of long-term finance for clean energy companies and projects [88]. Assets worth more than 1500 USDbn can theoretically be allocated to clean energy (see Table 2). However the OECD estimates that less than 1% of pension funds' global assets are allocated to infrastructure which includes clean energy projects [79,85]. In Europe there are fewer large pension funds and smaller total assets in pension funds than in North America. The exception is the Netherlands. It's fully funded system has resulted in the 3 largest pension funds covering over a half of the total AUM by pension funds larger than USD 50 billion in Europe [87]. Boermans and Galema [89] show in a study on Dutch pension funds that actively divesting from fossil fuels has no negative risk-adjusted performance implications.

The main exposure of institutional investors to clean energy has so far been via shareholdings of the debt and equity of listed utility companies [85]. The scope for this funding is limited by the willingness of institutional investors to buy new debt by and equity from utility companies [84]. Other ways include the investment via infrastructure project funds, direct investments into projects or asset-backed securities (special purpose vehicles) or unlisted (direct), intermediated and listed (direct) equity [85] (see Figure 8). Examples of the latter include World Bank Green Bonds or SolarReserve (Calpers) [85]. Direct investment is documented to be the most difficult type of investment for institutional investors due to the skills and resources required [90]. Some large pension funds active in this field are known to have developed significant in-house expertise but most smaller ones simply outsource the management of their investment portfolio. CPI suggested that AUM around USD 50 billion are needed in order to justify the costs of building a dedicated team to invest directly in clean energy projects [90].

In terms of sector/technology allocation, most of these investments are related to technologically mature wind energy. Infrastructure projects can in principle be financed through pension fund money, as these projects are bankable and offer the opportunity for long-term contracts with reliable counter parties, often with inflation protection [84]. Structural determinants limiting the exposure of pension funds to clean energy include liquidity constraints (investments that must be structurally short term), investment framework and governance process related constraints (i.e. the investment process and frequent benchmarking on indices make the investments short term) [84].

To overcome structural barriers to investments scholars suggest adjusting the prudential regulatory framework towards long term investment which entails addressing short term risk management and primary focus on solvency as well as bias for pro-cyclicality [88].

Institutional investors should be allowed to invest into less liquid assets, such as unlisted infrastructure and VC/PE, although pricing these assets might be problematic. In addition it is recommended that governments establish the appropriate regulatory, supervisory and tax frameworks for such investors to develop [88].

In parallel, some institutional investors (for example California's pension fund manager, CalPERS) decided to invest in clean technology funds as part of their ethical mandate [74]. It is important to note that green investment has traditionally been embedded in a broader approach of SRI (socially responsible investing) or ESG (environmental, social and governance) [35]. Investment volumes in ESG / SRI assets are a multiple of those in „pure" energy transition investments. SRI assets could be as high as EUR 7 trillion (two-thirds in Europe) [84].

4.5.3 Insurance companies

(Re-)insurance companies constitute a final category of institutional investors that theoretically could provide up to 1411 USDbn to finance clean energy which corresponds to current AUM in asset class 'alternative' (Table 2). In contrast to pension funds, insurance companies in Europe are based in a wider range of countries [87]. According to our analysis they have about the same amount of potential to invest into clean energy as pension funds and SWF. Their business of insuring weather and nature-related risks puts them in a unique position to experience the direct negative economic effects of climate change in their portfolio of clients. Hence they should have an incentive to invest to prevent increasing damage caused by climate change [84]. Availability of proprietary and internal historical data on the performance of clean energy from their insurance (underwriting) business units may also give some insurers a particular information advantage [87]. Similar to pension funds, insurance companies have mainly invested in wind-power projects and companies. However, they also invested in venture capital, private equity, public equity and debt in cleantech sectors [87].

Major barriers for investing into clean energy, other than the general considerations for institutional investors (section 5.4) revolve around specific regulation for insurers and pension funds (Solvency II). Regulations can exacerbate the focus on short-term performance, especially when assets and liabilities are to be valued at market prices [88]. Solvency II for insurers in the European Union could heighten the pro-cyclical nature of investment strategies – a phenomenon that has been diagnosed for pension funds as well. Various measures that have been implemented should help mitigate these potential effects, including a dampener on equity risk to prevent insurers from divesting of equities in a crisis period. Solvency II might also penalise infrastructure and other less liquid long-term assets which hampers clean energy investments [88].

4.6 State Investment Banks

A State Investment Bank (SIB) is a public entity established to facilitate private investment into in this case domestic low-carbon, climate-resilient infrastructure [40,91]. Governments have created SIBs with a narrow mandate focusing mainly on mobilising private investment by using interventions to mitigate risks and enable transactions. As an independent authority they usually have a degree of latitude to design and implement interventions and a focus on cost-effectiveness. However, their performance is regularly reported and evaluated by the respective governments [91]. Most SIBs have programs focusing on promoting investment in renewable energy and energy efficiency [92]. Examples include UK's green investment bank and the German KfW [93].

A recent study by Mazzucato and Macfarlane (2018) found that selected European SIBs could provide up to 240 USDbn in financing (Table 2), leveraging this into a multiple of private investment for clean energy [94]. Röttgers et al. [79] show that in more than 30% of clean energy projects financed by institutional investors, SIBs were involved.

Most state investment banks finance clean energy companies through concessional loans, followed by non-concessional loans and grants [91]. They also directly invest into projects and infrastructure by means of senior and subordinate loans, bonds and equity [91]. SIBs are evaluated using metrics such as the amount of private capital mobilised, return on (equity) capital, number of jobs created and GHG reductions. SIB's public reporting typically includes transparent calculation methodologies of their performance to build credibility [92].

Mazzucato and Penna [95] underline that SIBs 'shape and create' markets, rather providing fixes to market failures and that many SIBs play a 'mission-oriented' role, making key investments in new sectors. Correspondingly, Mazzucato and Semieniuk [22] highlight that public owned entities invested comprehensively in some high-risk renewable energy projects. Geddes et al. [94] find four major roles of SIBs: Capital provision and de-risking, they fulfil an educational role (risk assessment and internal expertise), a signalling role (reputation and crowding-in private finance and financing costs) and the role of being a first or early mover (new deal structures, manufacturers and developers). Specific instruments include loan loss reserves, guarantees, insurance, debt-subordination. They can also deploy transaction enablers such as securitisation (the bundling of small investments into a larger vehicle, co-investment and on-bill financing) [91].

4.7 Public equity

Public equity from listed/traded companies (mostly energy utilities) has been one of sources of corporate finance for the clean energy companies in the past decade [76] as many institutional investors such as insurance companies have invested broadly [87]. Olmos et al. [57] also highlights the function of governmental (public) equity investments in innovative companies to win back part of the RD&D support given in an earlier stage of the company lifecycle. Public equity markets play also an important role as an exit channel for initial public offerings for cleantech firms [71,96].

Cumulative investments amount to more than 26 USDbn (see Table 2) whereas the potential volume of this source of finance (represented by the current market capitalisation of European listed firms) can be as high as 9.5 USDtn (Table 2). Although public equity potentially covers a large market, it is not yet up to the task of catalysing clean energy investments which is mainly related to regulatory and disclosure issues. To allow for a meaningful comparison of green equities and benchmarking, standardised disclosure agreements need to be developed [82]. The listing of green bonds might a role for public equity markets to play in the clean energy investment field, provided green bond indices, rating or exchange lists are developed [82].

4.8 Intermediate channels

4.8.1 Green/climate bonds

An interesting initiative is emerging to allow institutional investors to make clean energy investments via the fixed income part of their investment portfolio – namely through the issuance of green bonds [83,84,87]. However less than 1% of global bonds are labelled green and less than 1% of the holdings by global institutional investors are clean energy assets [82]. Despite its current small size, the market for sustainable energy project bonds has growth potential [85] which is exemplified by the prominent role of asset backed securities such as green bonds in future clean energy scenarios [44]. As of June 2015, this additional climate bond universe stood at USD 509 billion. Renewable energy bonds made up USD 118.4 billion of this universe globally [83]. Estimates in this study based on EFAMA market data concludes that 11024 USDbn could potentially be invested by institutional investors according to their current mandate (see Table 2). Figure 9 shows that climate bonds have been used to finance mature hydro energy, but now also include solar and wind investments.

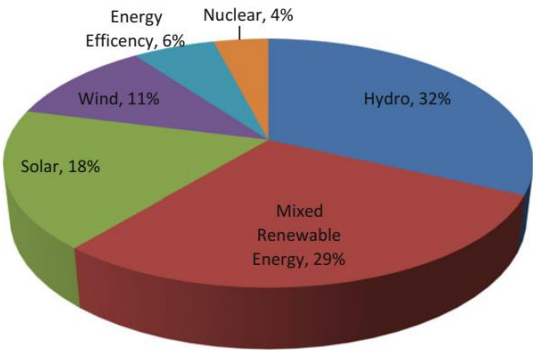


Figure 9: Share of different energy production technology in climate-aligned bond market Source: [35]

Green bond definitions and requirements for disclosure of the use of proceeds are the basis for developing a credible green bond market and for avoiding 'green washing' [82]. Globally, the most widely accepted ones are the Green Bond Principles and the Climate Bonds Initiative (CBI)'s standards. Barriers to the further expansion of green bonds markets lie in the limited awareness of the benefits of green bonds and the lack of guidelines for local green bonds and meeting the requirements thereof as well as a lack of green bond ratings, indices and listings. Furthermore international investors might have difficulties accessing local markets and domestic green investors might not have the capacity to invest in them [82].

To open up this route of financing for institutional investors and banks, policy makers would need to revise covered bond regulation allowing banks to issue covered bonds based on clean energy loans and allowing pension funds and insurer to buy them [85]. In addition, raising awareness, supporting the local development of green bond markets, reducing risk premiums and facilitating cost-efficient verification and reporting for green bonds alongside developing green bond indices, ratings, and stock exchange lists and finally promoting international collaboration to facilitate cross-border investment in green bonds are recommended to unlock this source of finance [82].

4.8.2 YieldCos

Since 2014, the YieldCo structure has emerged as an option for energy utilities and other clean energy asset owners to spin off operative assets from their balance sheets to develop, finance and implement new projects [35,85,97]. YieldCo's as listed intermediaries between investors and infrastructure projects that also rely on public markets. A YieldCo collects the stable cash flows and distributes them through public markets to shareholders as dividends while providing liquidity through the ability for investors to easily buy and sell shares in the YieldCo. YieldCos can enable institutional investors to invest equity directly in corporations to own operational clean energy assets. Institutional investors can thus access a portfolio of renewable energy projects through YieldCos as a new type of investment target with lower risks, especially construction risk [85]. YieldCos can also issue green bonds and potentially provide a major share in future clean energy equity investments [44,85].

The success of YieldCos largely depends on growth and the ability to acquire new assets that can deliver steady cash flows. The funds hence need to raise public offerings at high rates and maintain high share prices [85]. A recent study found that renewable energy index funds (ETFs) outperform YieldCos however investors in ETFs are exposed to the full range of risks faced by manufacturing and development, whereas YieldCos hold portfolios of low-risk, operational clean energy assets [97]. The authors asses that the YieldCo concept can thus provide a policy advantage by reducing the capital costs of renewable energy projects and providing low-risk returns to investors, thereby mitigating the public cost of achieving clean energy deployment policy objectives [97].

5 Discussion

The question guiding our inquiry was: *How much private finance is (roughly) needed for a low-carbon energy transition in Europe until 2050 but more importantly: in what mix should it be(come) available?* Building on empirical and modelling work, this paper set out to contrast investment needs and sources of finance for the energy transition in Europe and, more importantly, systematically explore where the money can come from and what kind of financiers need to be engaged in order to allow for an innovation-led energy transition. Most models used to make projections ignore the reality faced by financiers (investors), their constraints and existing portfolios (e.g. possibility of stranded assets). Hence here we discuss role, volumes, barriers to their engagement and solutions for various sources of clean energy finance [see e.g. ,19,35].

Table 3: Contrasting demand and supply of finance for RE in the EU/Europe

Source	Demand (2° comp. scenarios) (USDbn)	Supply: Lower bound (USDbn)	Supply: Upper bound (USDbn)
RD&D finance	*LIMITS:* 287-264 (energy supply) *LIMITS:* 392-466 (energy supply and demand)	1,48 (2014-2017)	5,8 (2014-2017)
Small- and distributed finance		0,33 (2014-2017)	8,11 (2014-2017)
VC and private equity		23,20 (2007-2015)	41,47 (high-tech 2007-2015) 423,17 (2007-2015)
Bank finance (debt)	Total Renewable energy (electricity): *LIMITS:* 2310	33,38 (2002-2012)	608,40 (2018)
Sovereign wealth funds		12,35	1310

	CD-Links: 2625 *IEA:* 2415 *PRIMES:* 5602 (Total supply-side investment requirements, see above)	(2007-2013)	(2018)
Pension funds			1581,04 (2018)
Insurers			1411,64 (2018)
State investment banks		78,02 (2018)	240,44 (2018)
Green/ climate bonds		509 (2014-2018)	11024,24 (2018)
Public equity		26,56 (2002-2012)	9588,70 (2018)

Notes: *Demand* represent the aggregated investment needs projected by three major models (data from Table 2); *Supply: lower bound* - investment volumes in RE/clean energy currently (latest available source) realised from this source; *Supply: Upper bound* - maximum potential from this source (current market volume/assets under management or general investments from this source in period indicated) given restrictions of their mandates.

In Table 3 we compare investments needs between determined contributions and 2° compatible scenarios into major RE technologies (Wind onshore/offshore, solar PV, biomass) and energy efficiency investments in the EU. The wind finance gap ranges between 53 USDbn and 333 USDbn. For solar PV the estimates vary between 94 USDbn and 823 USDbn. From the comparison of different biomass investment scenarios, a gap of 2 to 569 USDbn has been estimated. The differences in these estimates can largely be explained by different assumptions about energy efficiency investments and different levels of policy ambitions. Energy efficiency investments range from -11 USDbn to 1097 USDbn across major models.

Our analysis further shows, on the one hand, that the volumes are available in the order of magnitude needed for a successful energy transition, especially when it comes to institutional investors (see Table 3). On the other hand, the numbers also reveal a qualitative mismatch. There is ample capacity to invest in scaling mature technologies, but there are shortages in the (upstream) innovation finance, especially RD&D and venture capital and private equity. There the amounts are smaller, but the downstream impacts are not. There is no quantitative issue in freeing up these (public and private) resources and a little will go a long way in solving the most urgent bottlenecks; however typically the types of finance suitable for funding these type of projects are not so easy to mobilize in Europe's highly institutionalized, bank based and regulated financial sector [13,71,98].

5.1 Matching investment demand and supply

From the overview (Table 3) it becomes apparent that there is plenty of financing available especially in the later stages of technology lifecycle when the risks involved are comparably low. Especially institutional investors hold the biggest potential with up to 4.8 USDtn. That means even within the current composition of equities, bond and alternative investments, institutional investors could engage in financing large-scale (low-risk) renewable energy projects ([44,79,85]OECD, 2015a; Röttgers et al., 2018; Zindler and Locklin, 2016). Here, an effective reform of regulation and governance that enables institutional investors to engage more in unlisted long term equity and debt will make ample funding available to scale the technologies that can carry the energy transition. These could be realised through intermediate channels such as green bonds or YieldCos but institutional investors also heavily engage in public equity markets another underutilized source [44,97].

In the earlier stages of the technology lifecycle (with considerable risks) the problem is more urgent, especially when it comes to highly risky investments. Here only hardly scalable solutions (0.33-8.1 USDbn respectively 23-41 USDbn) such as small and distributed finance and venture capital are available, where the former are also able to address significant early stage risks [13]. Larger ticket sizes and higher risks can only be handled by (state) investment banks and some private equity funds. State investment banks have the potential to scale-up their investments significantly; however, their main role would be in mobilising private finance through co-investments, signalling and education [94].

Figure 10 depicts the sources of finance for the energy transition and links them to investment characteristics. The upper left corner represents the sweet spot for institutional investors that includes wind farms, utility scale PV or first-generation biofuel refineries. Investments in this quadrant come in big tickets and have low operational, market and regulatory risks. These projects also feature a generally lower risk profile. In this category we also find component manufacturers for wind and solar or energy efficiency services.

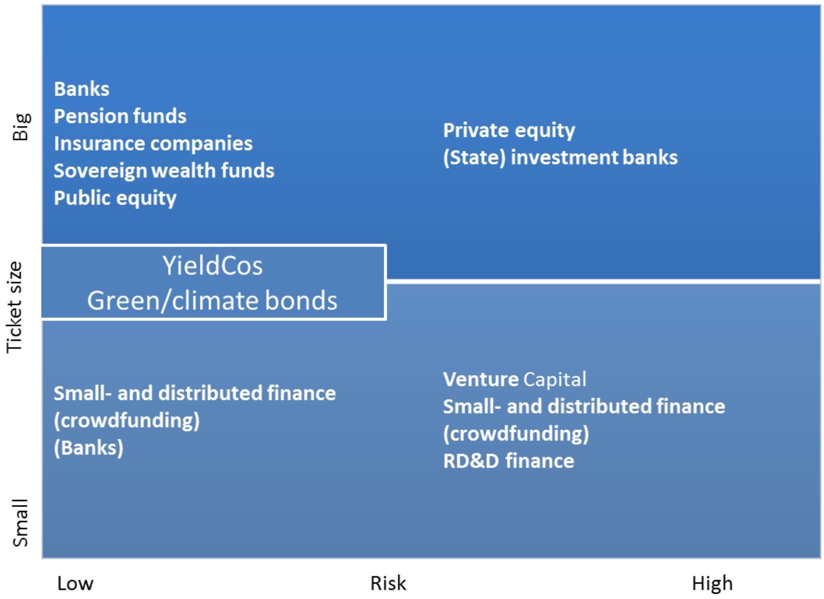


Figure 10: Sources of finance for the energy transition (framework adapted from [73,76])

The bottom right quadrant exhibits innovative technologies such as fuel cells, power storage or electric drive trains that are at a small-scale demonstration level and carry significant technical and market risk. Next to VC that focuses on rapidly scalable solutions, small- and distributed finance emerged to service this niche alongside continued (public) RD&D support.

The upper right quadrant features the 'hard-to-finance' projects and companies combining large scale with a high risk such as offshore wind farms, advanced biofuels or first commercial plants of unproven technologies. Here to some degree only private equity funds or (state) investment banks can effectively engage, whereas low risk small scale projects, mostly in energy efficiency and residential building improvement, both traditional banks and modern platform-based crowdfunding can play a role. As in the latter case, innovation in the financial sector itself is an important channel for making policy, we discuss this quadrant in more detail below.

To bridge the gap between large ticket size requested by investors and the small scale and illiquidity of many energy efficiency retrofitting projects securitized investments vehicles such as YieldCos and Green Bonds could play role in combining investments into larger tickets [35,84,87,99]. These funds and bonds could then be traded on public stock exchanges providing clean energy investments with the necessary liquidity characteristics.

5.2 Enabling large-scale investments and small scale(!) investments

From our analysis of different sources of finance there are three major ways of unlocking their potential. First, initiatives promoting socially responsible investments from within the sector (such as pension funds and sovereign wealth funds) that base their investments also on ESG criteria could be scaled up [82]. Second, mandates and regulation currently blocking investments in unlisted assets with no market price could be changed. Third, standardisation and securitisation would allow financial intermediaries to bundle smaller investments into larger funds that make it attractive for larger (institutional) investors to invest and allow them to simultaneously meet their liquidity targets [35,84,88].

In addition to unlocking the potential for larger scale low-risk investments, an innovation-led energy transition needs risk-carrying capital in smaller tickets [13,23,100]. Here major barriers lie in their sources of finance: free equity from individual retail investors or institutional funding from pension funds, insurance companies or sovereign wealth funds. Much of the financial means that could be used for experimentation are locked up in structures that channel them towards stable yield, low-risk assets. Also exit possibilities such as public equity markets are a major hurdle for engaging these sources further. They also depend on complementary large-scale infrastructure investments which is an example of the interdependencies between small- and large-scale and low- and high-risk finance.

Finally, a recurring theme across sources of finance is the missing expertise with technologies, investment vehicles and transition paths [e.g. 73,83]. Röttgers et al., (2018) show they prove to be major barrier to more extensive engagement. Especially the risk assessment e.g. weighting technical, regulatory and market risks vs. climate change related risks on an aggregated level is underdeveloped and knowledge on guarantee schemes to reduce these risks is not widely disseminated.

6 Conclusions and implications

Our analysis for the demand and (potential) supply for clean energy finance in Europe shows that sufficient money is in principle available. However, matching investment demand and supply in a qualitative sense, proves challenging. The resources are sometimes not available in the form they are most needed. We show there is a lack of private small-scale equity investment to promote RD&D, whereas low risk but small ticket financing of energy efficiency investments would require banks to complement platform-based intermediation. We also note that the large scale, low risk debt investments are not yet free to move into suitable renewable energy projects and tend to be pushed more into existing real estate and government debt. New forms of intermediation and a set of enabling reforms (mainly addressing regulatory issues and standards) could help unlocking under-utilized small-scale and large-scale sources and facilitate the energy transition in Europe.

6.1 Policy implications

Earlier research pointed out that current financial efforts fall short in reaching the in the Paris agreement stated pathways for 2° world [11,21]; however our analysis shows that the potential for sources of finance are available in ample supply, even if we take their specific constraints and investment preferences into account. As a policy maker, mobilizing private finance for clean energy can be approached from two perspectives [e.g. 12,13,23]: Policies targeting the real economy (the energy sector) as well as policies target framework conditions for the different sources of finance.

First, *climate and energy policy* play a crucial role in attracting investors [60,99,101,102]. These range from putting a price or tax on carbon [99] to direct instruments such as feed-in tariffs, renewable portfolio standards, other regulations (e.g., stricter appliance, building, and vehicle efficiency standards) or RD&D subsidies [102]. Almost all of the investment scenarios reaching a 2° compatible path assume a deployment of a policy portfolio for innovation and diffusion of clean energy [4,6,11,18]. Also our analysis assumes such political commitment. However, we also emphasise that the policies implemented, should also consider the implications for investors. A steady hand and long run reliability of policy programs is essential for their effectiveness, perhaps even more so than the amounts of public money spent. If governments better understand the realities of investors in different sources of finance, they can shape the essential energy transition policies in a way that minimizes policy risk, which is a key barrier to investment for all sources of finance.

Second, policy makers need to specifically address regulatory barriers to clean energy investment. These include adjusted liquidity requirements for institutional investors, benchmarking and KPIs, asset risk classification reflecting climate risks for asset managers and banks as well as the prudential regulatory framework valuing long-term investments and lending for the banking sector.

This paper also adds recommendations specific for the major sources of finance. Against the trend of cutting public support for energy R&D over the past 30 years, scholars and practioners alike recommend a strong role of the government in innovation *(RD&D)* finance. Given the large financing gap of many clean energy innovation projects, public grants and contracts alongside more basic R&D should finance a significant part of them [22,56]. Other instruments include public loans, equity investments, prizes and tax credits or rebates that can efficiently support innovation processes [57].

For *small-scale finance*, such as crowdfunding, policy makers need to strike a balance between protecting the individual investors and the development of new forms of cooperative finance (energy cooperatives) that attract these investors. Standardizing these cooperative approaches would reduce transaction costs and enable a (decentralised) scaling up of in particular decentralized energy efficiency investments. Furthermore locking-up less of savings in pension funds would free it for long-term investment and/or experimentation through small-scale finance.

Engaging risk finance *(VC/PE)* requires on the one hand an adjustment on the level of the European financial ecosystem i.e. increasing the availability local (institutional) anchor investors as well as the exit opportunities through strengthening European public equity markets. Furthermore, a reform in tax regime for early stage investments and entrepreneur-friendly bankruptcy legislation would encourage VC investment across the board, also for energy transition. In addition, SBIR grants, university R&D support, certain (de)regulatory actions in the energy sector, large-scale demonstration projects, and/or procurement decisions would also be beneficial for the early stages of technology deployment that VC investors target [74,103].

Banks suffer from a maturity mismatch (short-term deposits vs. long-term loans to clean energy companies and projects) and an unattractive risk/return profile (non-bankable) of clean energy investments. In addition to addressing the risks through long-term oriented policy reforms [40] and long-term loan guarantees [74], more structural policy measures include more favourable macro-prudential regulation e.g. by increasing the risks weights for ’brown’ loans [13,40,80].

Channelling *institutional investors (pension funds, insurance companies, sovereign wealth funds)* financial resources into clean energy require clear environmental and economic policy signals for investors regarding the strategic framework for green investment. Policy makers could also encourage market participants to promote the adoption and implementation of voluntary responsible investment principles or promote increased awareness and capacity building among key intermediaries such as stock exchanges, credit rating agencies, equity analysts and investment consultants [82]. To address liquidity constraints legal barriers regarding intermediary fund structures such as YieldCos need to be solved. Finally policy makers need to support efforts to standardise contracts and project evaluation structures, e.g. creating aggregation and ‘warehousing’ facilities and improving market transparency (data on performance, risks and costs of sustainable energy investments across available channels) [85].

Many academic studies and reports highlight the important role of *state investment banks (SIBs)* for co-investing, signalling and information provision and risk reduction in the clean energy sphere [22,94,95]. These provide an opportunity to address not only upstream (innovation-related) barriers but also accelerate investments and lending to mature renewable energy projects and should hence be a corner stone of a policy mix [79].

6.2 Implications for financiers

From our analysis follow a number of implications for financiers. First, invest into knowledge about climate change and clean energy for future investments in the form of human capital that enables an improved risk and return assessment. Relatedly adhere to sustainable/responsible investment practices and join the respective networks might be a way to approach this.

Second, engage and partner with (semi) public investors such as EIB, state investment funds or sovereign wealth funds that have the capacity and knowledge to execute the due diligence or take the first loss in the case of under-performance of an investment. Almost all scenarios predict an increase of clean energy share from the major RE sources wind, solar and biomass. To be part of that transition seems to be good business. But sharing risks with public investors is a way to do so responsibly.

Third, financiers need to develop innovative financial products to bundle small tickets into bigger funds, as scale and due-diligence costs are often barriers to investments in clean energy companies, projects and infrastructures. Structured finance can help increase investment volumes by reducing such due diligence costs. These mechanisms can also help securitise renewable energy assets for the purpose of trading them in capital markets [83].

Fourth, develop a methodology to standardize the assessment of projects/companies or intermediate channels such as green/climate bonds or YieldCos. This would reduce transaction costs and hence increase the feasibility of smaller investments, even by institutional investors such as pension funds or insurance companies. This proves to be especially important since many of the scenarios require decentralised investments into energy efficiency (e.g. retrofitting buildings etc.).

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Appendix

Table A.1: Calculations of sources of finance

Source	Calculation lower bound	Calculation upper bound
RD&D finance	Summary country RD&D budgets IEA 2018 Renewable energy sources RD&D	Summary country RD&D budgets IEA 2018 Total energy RD&D
Small- and distributed finance	Nigam et al. 2018 (p.204): List of crowdfunding platforms in Europe related to renewable energy Grand total calculation	
VC and private equity	EVCA energy and environment VC/PE investments 2007-2015	EVCA high-tech VC/PE investments 2007-2015 EVCA hall VC/PE investments 2007-2015
Bank finance (debt)	Corporate debt deals clean energy (BNEF 2013)	Volumes of new euro-denominated loans to euro area non-financial corporations (EUR billions; new business) Revolving loans and overdrafts
Sovereign wealth funds		Preqin (2018) THE 2018 PREQIN SOVEREIGN WEALTH FUND REVIEW (p.17) Total assets under management in Europe
Pension funds	(OECD, 2015a) p. 51	European Fund and Asset Management Association (Asset Management in Europe 10th Edition Facts and figures pp. 5,7) 28% (pension funds) x 25.2 EURtn = 7056 EURbn; 21% (Other asset allocation) x 7056 EURbn = 1481,76 EURbn
Insurers		European Fund and Asset Management Association (Asset Management in Europe 10th Edition Facts and figures pp. 5,7) 25% (insurance compaies) x 25.2 EURtn = 6300 EURbn; 21% (Other asset allocation) x 6300 EURbn = 1323 EURbn
State investment banks	Mazzucato & Semieuk (2018 p.12) Investments into RE so far (-2018) 7,6% (state banks) x 962,2 = 73.12 EURbn	Macfarlane & Mazzucato (2018): In EURbn: KfW 81 + EIB 68,76 + Cassa Depositi e Prestiti 30.1 + Nordic Investment bank 3.373 + BPI France 42
Green/ climate bonds	Climate Bonds initiative: BONDS AND CLIMATE CHANGE THE STATE OF THE MARKET (2018 p.5): Fully aligned issuers	European Fund and Asset Management Association (Asset Management in Europe 10th Edition Facts and figures pp. 5,7) 41% (bonds) x 25.2 = 10332 EURbn
Public equity	Frankfurt School-UNEP Centre/BNEF, 2018 (p.XX): Global public equity in clean energy 2004-2017	Federation of European Securities Exchanges (FESE, 2018, p European Capital markets factsheet 2014-Q4 2018 (p.1) Market capitalisation on European Security Exchanges Q4/2018

Note: Exchange rate for transforming EUR into USD is 1,067 (2015 average taken from https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates)