Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research

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ABSTRACT

This paper introduces the special issue on Strategic Choices for Renewable Energy Investment, which is a collection of best papers presented at an international research conference held in St. Gallen (Switzerland) in February 2010. Substantial private investment is needed if public policy objectives to increase the share of renewable energy and prevent dangerous anthropogenic climate change are to be achieved. The aim of this paper, and the entire special issue, is to draw scholarly attention to the processes underlying strategic choices for renewable energy investment, and how they are influenced by energy policy. We disentangle the role of risk-return perceptions, portfolio effects and path dependence in explaining energy investment decisions, and suggest that the heterogeneous universe of investors requires a segmentation of policies. The paper outlines some of the rich opportunities for further research in this emerging area.

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1. Introduction

Policy makers around the world are recognizing the challenge of addressing climate change. At the same time, more than 80% of global energy supply relies on depletable fossil fuels, with resources being unevenly distributed across world regions, creating significant energy security challenges. Finally, the accident in Fukushima has refreshed our memory with regard to nuclear risk. Increased investment in renewable energy technologies, in combination with energy efficiency, can help to meet future energy demand while at the same time minimizing the risks of conventional energy supply as highlighted above. Such investment has seen significant growth over the past decade, often supported by favorable policy frameworks. On the other hand, policy has not only created opportunities, but also posed risks for renewable energy investors. How do investors take decisions based on those risks and opportunities? How much of their decision process can best be explained by traditional economic models of full rationality, and what is the influence of bounded rationality and path dependence in the perception of risks? And what can policy makers learn from insights about investor decision-making to design even better policies? The starting point for this special issue was our observation that such important questions are currently not getting the level of scholarly attention that they deserve. More research is required in order to provide the kind of

fruitful environment necessary to deliver on governments' ambitions to mitigate climate change and address the transition to a renewable energy supply.

While arguably there is a wide range of research opportunities to be addressed here, we would encourage scholars (as well as policy makers) to pay particular attention to *strategic choices*. Strategic choices are characterized by one-off, new, ambiguous and complex decision contexts; they require resource commitment (or the decision not to commit), and they are not easily reversible (Bansal, 2005; Eisenhardt and Zbaracki, 1992; Mintzberg et al., 1976). When it comes to energy investment, not all decisions made by financial, corporate or retail investors are equally important. Whether a venture capitalist decides to set up yet another fund in biotechnology or endeavors to start a new fund in clean energy has more impact than where he makes an incremental investment in an existing fund. An oil company's decision to enter or exit the solar industry has more far-reaching consequences than another company's decision to extend its manufacturing facilities by one more assembly line. A utility's decision whether to invest in a new coal-fired power plant or an offshore wind park determines output for decades to come. Where consumers choose to invest in a new house relative to their place of work determines their transportation-related energy consumption (and the possibility to satisfy that demand with renewable energy) for several years. The strategic portfolio allocation of public research funding agencies among conventional and renewable energy technologies carries more weight than support for one particular research project or another, and – due to path dependencies – such allocation decisions are not easily reversed ever after. Properly understanding the determinants of

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such far-reaching, strategic choices will be particularly helpful in creating effective frameworks for renewable energy investment.

2. Renewable energy investment and policy: What do we know?

2.1. Current status of renewable energy investment

Over the last few years, investment in renewable energy technologies has steadily increased in both developed and developing countries. According to the Intergovernmental Panel on Climate Change (IPCC, 2011a), renewable energy accounted for 12.9% of global primary energy supply in 2008, with the largest share coming from biomass. While new renewable energy sources such as wind and solar of energy only account for a small fraction of global energy supply, they have recently experienced significant growth, especially in countries with active renewable energy policies. Denmark has seen the share of wind power grow to about 20% of the country's electricity supply in the 1990s, while Germany has increased the share of renewable energy from 3.1% to 16.8% of electricity supply and from 2.1% to 9.8% of heat supply between 1990 and 2010 (BMU, 2011). China has seen strong domestic growth in the wind energy sector, with installed capacity nearly doubling from 25.8 to 44.7 GW in 2010 alone, overtaking the US as a global market leader for wind energy (GWEC, 2011). Apart from energy policies, technological improvement and cost reductions have been a strong driver for growth. For instance, the project cost for onshore wind energy has decreased by around a factor of three between 1982 and 2002 (Wiser and Bolinger, 2008), and the cost of solar photovoltaic (PV) modules has decreased by a factor of nine, with a 30% cost decrease in 2009 alone (IEA, 2009a). Costs are expected to decrease further as a result of technology development, deployment and economies of scale.

Investment in renewable energy was fairly limited until the early 2000s. According to Bloomberg New Energy Finance (2011), total investment in clean energy amounted to USD 52 billion in 2004. Since then, investment in clean energy has recorded a substantial growth, reaching USD 180 billion in 2008 (almost a four-fold increase). In the light of the financial crisis, growth in renewable energy investment almost came to a standstill in 2009, but rebounded in 2010 with an annual growth rate of about 30%.

While the global financial crisis seems to have had limited overall impact on the renewable energy investment community, it led to some significant structural shifts (UNEP and Bloomberg New Energy Finance, 2010). While for example new investment in US wind power showed a sharp decline in 2009 and 2010, the Chinese market continued to exhibit high growth rates. Also, investment in solar photovoltaics boomed in 2010, with a particular focus on new manufacturing capacity in China and new installations in Germany, which saw 7.4 GW of new capacity added in 2010 (BMU, 2011), a 75% increase over 2009 levels.

While government used to be the most important source of funding a decade ago, private investments have now become the largest source of capital for renewable energy projects. This growth is the result of two factors: on the one hand, technology improvement has led to increased reliability and declining costs of many renewable energy options, and on the other hand, renewable energy policies have successfully created new market opportunities, which in turn spurred private sector investment (Fig. 1).

Wind energy has been the engine of growth in renewable energy investments for more than a decade now. While the global financial crisis has slowed down that growth, wind power generation capacity continued to grow by over 30% in 2009 and by 24% in 2010 (GWEC, 2011). In the European Union (EU), new wind generation capacity in 2009 reached over 10 GW, with an annual average market growth of 23% over the last 15 years (EWEA, 2010). Wind installations represented 39% of total generating capacity added in Europe in 2009, more than any other power generation technology. Investment in EU wind farms in 2009 totaled €13 billion, of which €11.5 billion in onshore and €1.5 billion in offshore wind energy projects. In 2010, another 9.9 GW of new wind power capacity was installed in Europe, indicating the first year in which new installations were slightly below the previous year (EWEA, 2011).

Although smaller than wind in absolute values, investments in solar photovoltaics (PV) have been experiencing dynamic growth. PV is the fastest growing renewable energy technology, with a fourteen-time capacity increase in the last 10 years, and an annual average growth of 30% over the same period. By 2050, solar photovoltaics and concentrated solar power (CSP) are each expected to be in the same order of magnitude as wind energy in terms of contribution to electricity generation and greenhouse gas reductions (Frankl and Philibert, 2009).

Fig. 1. Global new investment in clean energy 2004–2010. (Includes corporate and government R&D, and small distributed capacity. Adjusted for reinvested equity. Does not include proceeds from acquisition transactions).

Source: Bloomberg New Energy Finance (2011).

2.2. The future of renewable energy investment in a carbon-constrained world

In a future carbon-constrained world, investment in renewable energy is supposed to show further growth. Keeping CO₂ emissions to a level consistent with a 2 °C temperature increase requires an amount of global investments in clean technologies in the order of USD 400–500 billion per annum until 2020 (IEA, 2009b). The IPCC's recent Special Report on Renewable Energy Sources estimates that global investments in renewable power generation technologies will range from USD 1360 to 5100 billion in this decade, and from USD 1490 to 7180 billion in the decade 2021–2030, with the higher values being consistent with a stabilization of CO₂ concentration at 450 ppm (IPCC, 2011a). While five to seven trillion dollars in two decades is a large number, annual investment is equivalent to less than 1% of global GDP even in those climate change mitigation scenarios that assume renewables to become the dominant source of energy by the middle of this century. Also, it may be noted that these numbers for renewable energy investment are in the same order of magnitude as those published on total energy investment by the IEA (2003), who estimated investment in energy-supply infrastructure worldwide (including conventional energy sources) over the period 2001–2030 at \$16 trillion. Therefore, while mobilizing private investment is obviously not trivial, the true challenge policy makers are facing is not primarily about “paying a green premium”, but one of influencing strategic choices of those investors who will deploy capital anyway, and are selecting between opportunities in conventional and renewable energy projects.

Scaling up sustainable energy investments requires important changes in the social and institutional context (Krewitt et al., 2007). As pointed out by Grubb “technological advances, and in some cases breakthroughs, are certainly needed: but the revolution required is one of attitudes” (Grubb, 1990, p. 716). This change in attitudes concerns a multitude of actors, from policy makers to citizens, industry and market operators and investors. Managing social acceptance of renewable energy innovation, and especially acceptance by the financial community, may therefore be an important success factor for future energy and climate policies (Wüstenhagen et al., 2007).

2.3. Linking renewable energy investment and energy policy

In measuring the effectiveness of renewable energy policies, most of the literature has used installed capacity as the dependent variable rather than explicitly addressing investment. For example, a large number of country-level case studies have been carried out across different geographies, renewable energy technologies and policy instruments (Jacobsson and Lauber, 2006; Wüstenhagen and Bilharz, 2006; Breukers and Wolsink, 2007; Lipp, 2007; Toke et al., 2008), and asked whether some policy instruments (for example, price-driven vs. quantity-driven) work better than others in bringing about new capacity. Much of this literature suggests that the answer may be: “it depends” (IPCC, 2011b). For example, economic modelers would argue that trading schemes such as Renewable Portfolio Standards (RPS) may be an effective way of minimizing cost (Palmer and Burtraw, 2005), while several authors in Energy Policy have pointed out that their implementation in real life suffers from limitations like market power and transaction cost (Jensen and Skytte, 2002; Menanteau et al., 2003; Verbruggen, 2004; Jacobsson et al., 2009; Bergek and Jacobsson, 2010). On the other hand, feed-in tariffs have brought about significant new capacity in Germany, but they have also been criticized for their cost implications especially in the case of PV (Frondel et al., 2008), and their implementation in other countries shows a variety of outcomes (Rowlands, 2005;

Campoccia et al., 2009; Lüthi, 2010). Apparently, the devil is in the details of policy implementation (Menanteau et al., 2003; Dinica, 2006; Ringel, 2006).

What is different then about using investment rather than capacity as the dependent variable of policy analysis? Can any additional insights be gained by moving from tracking megawatts to dollars (Usher, 2008)? A possible answer to this question relates to a recent stream in the energy policy literature that highlights the importance of risk in policy design. Variations in policy outcomes, these authors suggest, are strongly influenced by variations in the level of risk that different policies imply for investors. Therefore, while two policy instruments, such as feed-in tariffs and green certificate systems, might be expected to lead to similar outcomes in economic models without proper consideration of investment risk, one may actually outperform the other if risk is accounted for. This has been offered as an explanation for why feed-in tariffs have resulted in higher levels of new renewable energy capacity than green certificate systems (Mitchell et al., 2006). Lower risk translates into lower financing cost for renewable energy projects by affecting investors' cost of capital (Wiser and Pickle, 1998; Langniss, 1999; De Jager and Rathmann, 2008). Policies that effectively reduce (perceived) risk for investors are therefore more likely to result in large-scale deployment of renewable energy. In this paper, and the special issue of Energy Policy that it introduces, we add to previous calls for including an investor perspective in assessing the effectiveness of energy policies (IEA, 2003; Dinica, 2006; Hamilton, 2009; Gross et al., 2010). The empirical evidence about how policies and their risk are actually perceived by investors and project developers has been limited so far (e.g. Bürer and Wüstenhagen, 2008, 2009; Lüthi and Wüstenhagen, 2011).

An interesting feature of looking at investment rather than installed capacity is that it works almost like a time machine, or a crystal ball (Usher, 2008). By measuring today's investment in project finance, researchers can gain insights into tomorrow's installed capacities. Today's investment in manufacturing capacity for renewable energy equipment (like wind turbines or solar cells) gives an indication for which installations are to be expected in 2–5 years. And today's investment in venture capital is a precursor of technologies that will be deployed 5–10 years down the road. Finally, moving from revealed to stated preferences, as some papers in this special issue do (Masini and Menichetti, this issue; Looock, this issue), can stretch this effect a little further on the time axis. Especially in the renewable energy sector, where markets are facing dynamic growth in recent years only, an analysis of investment (decisions) rather than – or in addition to – the traditional ex-post analysis of installed capacities can therefore help to alleviate the inherent problem of data availability and allow policy makers to take informed decisions with the benefit of foresight.

3. A conceptual model of strategic choices for renewable energy investment

3.1. Starting point: Renewable energy investment as a function of risk, return and policy

When trying to understand what determines current levels of renewable energy investment, a basic model is to represent investments as a function of risk, return and policy (cf. Fig. 2). Risk and return have long been established as fundamental determinants of investments in finance theory. Investors, so the argument goes, rationally weigh the levels of risk and return of possible investment opportunities, and will pick those opportunities that provide the best return for a given level of risk. Another way of putting this is that investors compare investment

Fig. 2. A simple model of renewable energy policy and investment.

opportunities by looking at their risk-adjusted returns. In energy, investment opportunities in renewables tend to be at a disadvantage compared to conventional energy because of environmental externalities. Therefore, there is a case for energy policy to correct those externalities. The effect of such policies on investment, in the basic model, is to make the risk-return equation more favorable for renewable energy investors, for example by increasing the returns for renewable energy investment (e.g. through feed-in tariffs) or by reducing the risk (e.g. through loan guarantees). The relative influence of policy vs. “pure” risk-return considerations on renewable energy investment is subject to some debate in the literature. While some observers see policy as the essential driver of RE investment (IPCC, 2011b), others, especially in the investment community, emphasize the role of private capital that is seeking opportunities with or without policies (e.g. some of the venture capital investors interviewed by Wüstenhagen and Teppo, 2006). Despite the nuances, there seems to be agreement that policy is – at least for the time being – one of the important drivers, but in order to reach the order of magnitudes of investments outlined in the previous chapter, markets cannot be driven by policy alone to infinity. Therefore, further investigating the subtleties of the policy-investment nexus is an endeavor worth undertaking.

The following section will drill deeper into some of the drivers of renewable energy investment, including but not limited to policy. This will ultimately result in a more sophisticated conceptual model for investigating strategic choices for renewable energy investment (cf. Fig. 4), which serves both as a framework for understanding papers in this special issue, but also as a starting point to identify promising avenues for further research.

3.2. Portfolio aspects

A first extension of the basic risk-return model of investment comes from portfolio theory. Markowitz (1952) was the first to highlight the concept of portfolio diversification, noting that risk can be reduced by combining different assets. Therefore, there is a systematic difference between the risk-return ratio of one single investment and that of a portfolio of investments. This is important for renewable energy investment on two levels:

First, adding renewable power generation assets to a portfolio of conventional power generation assets may provide a diversification effect. Traditional engineering-economic models of valuing power generation assets, as they are employed by most electric utilities, do not account for this effect, hence potentially undervaluing renewables (Awerbuch, 2000a, 2000b, 2004). For financial investors, on the other hand, the idea of portfolio diversification is deeply embedded in the way they assess opportunities. This might explain why some financial investors, such as insurance companies and pension funds, have become more proactive than utilities when it comes to investing in renewable energy assets.

Second, there is diversification among different renewables—the risk-return ratio of a wind park and a set of solar power generation facilities together are likely to be more favorable than the individual

ones. Laurikka (2008) calls this the diversification of plant-specific risk.

Failure to properly value diversification effects may result in underinvestment in renewables.

What are the implications of portfolio diversification effects for policy that intends to stimulate renewable energy investment? First, failure to value portfolio effects may constitute one of the cognitive barriers to renewable energy investment based above. Second, since financial investors tend to be more experienced in valuing portfolio effects than incumbent utilities, policy makers aiming at increasing levels of RE investment may be well-advised to target their policies at a wide range of investors, and not just incumbent players in electricity markets. Third, discussions about the cost-effectiveness of renewable energy policies that focus on “additional cost” based on a comparison of additional cost per kilowatt hour may be missing an important part of the equation, and should reconsider their key metrics to capture the value of portfolio diversification (and avoided fuel price risk).

3.3. Investor heterogeneity and the segmentation of policies

Another aspect where Fig. 2 depicted an oversimplified model of reality was that investment decisions about renewable energy are not taken by one type of financial actor alone, but instead there is heterogeneity among investor types. This is true for investors along the different stages of the innovation chain (see Fig. 3): for example, venture capitalists investing in early-stage technology firms require different policies (Bürer and Wüstenhagen, 2009) than project financiers who deploy mature technology. When it comes to large-scale deployment of renewables, the number and diversity of investors that need to be targeted increases once more. For example, corporate (e.g. electric utilities), financial (e.g. insurance companies, pension funds) and retail investors (e.g. homeowners) all invest in solar photovoltaics, but they are likely to differ in their policy preferences. While empirical evidence is rare so far, it might be worth systematically investigating such differences, which might refer to required rates of return, preferences for initial down-payments vs. recurring tax breaks, etc.

Borrowing from marketing terminology, there seems to be a case for segmentation. Just as consumers can be segmented to increase the efficiency of marketing efforts, thinking about ways to identify relevant investor segments may increase the efficiency and effectiveness of public policies to leverage private capital for the growth of the renewable energy market.

3.4. The role of cognition, risk perceptions and bounded rationality

An important insight from decades of research into behavioral finance is that investment decisions are made by human beings who act under bounded rationality (Simon, 1955). Rather than some “objective” measure of risk and return, a behavioral perspective would suggest that *perceptions* matter, and that perceptions of risk and return are influenced by cognitive factors. This has been demonstrated for a wide range of decisions under uncertainty, starting with the seminal work of Kahneman and

Fig. 3. Segmentation of financial investors along the innovation chain. Adapted from Bürer and Wüstenhagen (2009) and Grubb (2004).

Tversky in the 1970s (Tversky and Kahneman, 1974). Among the set of cognitive biases (McFadden, 2001) that have been identified by behavioral finance scholars are anchoring-and-adjustment, availability, representativeness and status quo-biases (Pitz and Sachs, 1984; Barnes, 1984; Samuelson and Zeckhauser, 1988; Katz 1992). These biases can lead to conservatism in adjusting to new information (Tversky and Kahneman, 1974; Kahneman, 2003) and to decisions in which losses are weighted differently than gains (Kahneman and Tversky, 1979). Pursuing this line of reasoning further, the behavioral economics and finance literature has investigated how real financial markets deviate from classical economic models, including investor behavior in stock markets (Lakonishok et al., 1994; Jordan and Kaas, 2002; Chan and Lakonishok, 2004), currency speculation (Froot et al., 1992; Bikhchandani et al., 1992; Bikhchandani and Sharma, 2001) and managerial decision-making (McNamara and Bromiley, 1999).

What are the implications for renewable energy investment and policy? If one accepts that investors act under bounded rationality, what ultimately matters is the impact of policies on perceived levels of risk and expected returns. While actual risk and return certainly still matter, not all investors will have all the information available to comprehensively judge the actual levels of risk and return before taking an investment decision in renewable energy. Therefore, in addition to trying to lower actual risk or increasing actual return, it is important for policy makers to manage expectations. Risk-return perceptions can, for example, be negatively influenced by frequent policy changes or unclear targets. The value of long-term policy stability, which may not be entirely obvious from classical economic models assuming full rationality, becomes evident from a bounded rationality perspective. Similarly, green public procurement strategies may have positive effects on private sector investment in renewables by reducing perceived risk and adding a stamp of credibility to renewable energy technologies. Policy makers can also try to address cognitive barriers directly, for example by investing in education and training for financial decision-makers, or by collaborating with opinion leaders in the financial community.

3.5. Path dependence in energy investments

One important implication of a bounded rationality perspective is the existence of path dependence (North, 1990; Goldstone, 1998), i.e. that past events have an impact on present choices. For example, Wüstenhagen and Teppo (2006) have identified evidence for path dependence in the venture capital market, which slowed down the flow of venture capital investments into the newly emerging renewable energy sector. Lovio et al. (2011) discuss effects of path dependence on Finland's attempts to diversify its economy away from fossil fuels. Path dependence can also lead to lock-in, and it has been suggested that the world is currently locked-in to a high-carbon economy (Unruh, 2000), which is difficult to transcend (Unruh, 2002). Path dependence may not only occur on the level of industries or innovation systems, but also on the firm level. For example, past investments in fossil fuels may influence the risk-return perception of decision-makers in oil companies, leading them to see more opportunities on their previous path than in the less familiar territory of renewable energies (see Pinkse and van den Buuse, this issue).

What are the implications of path dependence on policy makers' efforts to stimulate investment in renewable energy? A first recommendation would be for policy makers to be sensitive for history, in that new technologies like renewables do not enter the market in a vacuum, but instead there are vested interests of incumbents and risk-return perceptions based on past experience that determine today's choices. Therefore, simply providing a "level playing field" for renewables and expecting the invisible hand of the market to result in an optimal allocation of capital may not be enough, as boundedly rational actors, in case of doubt, will still stick to their past patterns of investment. Systems tend not to switch from one path to another by themselves, but need some initial impulse to get a new path started. As a consequence, while some authors view generous feed-in tariffs as wasteful overfunding for renewables, a path-dependence perspective may suggest that this is the kind of initial impulse that is needed to overcome inertia in the financial system. Just like building a new

Fig. 4. A more differentiated model of renewable energy policy and investment.

road needs some initial investment, path creation in the energy system is not for free.

3.6. Conclusion: A more differentiated picture of renewable energy policy and investment

Taking the considerations of the previous sections together, there seems to be a case for a more nuanced picture of the antecedents of renewable energy investment (see Fig. 4). As a starting point, risk and return are important drivers of investment decisions. Therefore, policy makers aiming at an increased share of renewable energy should do what they can to reduce risk and provide adequate returns. Creating a level playing field, and helping the market to value positive externalities of renewables, is also important. However, the story does not end here. We live in a world of bounded rationality, and therefore, perceptions matter, and policy needs to take such perceptions into account. Surveying investor attitudes and preferences can help to identify which risks are perceived as particularly relevant, and therefore help policy makers to prioritize their efforts. On the other hand, especially when it comes to long-term decisions, investor preferences should obviously be regarded as complementing, rather than being a substitute for, strategic choices made by policy makers themselves. Portfolio effects and the idea of diversification adds another layer to the understanding of investment choices, because investment in more than just one asset has different implications. Finally, not all investors are the same, and similar investment opportunities are valued differently by different investors. These differences are driven by rational aspects such as the effects of portfolio diversification, but also has its boundedly rational component, e.g. in the form of path dependence and prior investment choices. To conclude, we suggest that an effective policy mix is based on a thorough understanding of investor realities, including cognitive factors, and includes segmentation.

4. This special issue of energy policy

4.1. Business models and investment in energy innovation: Rational and behavioral aspects

In their paper, Pinkse and van den Buuse (this issue) investigate the different strategies and behaviors of three main oil and gas incumbents investing in the solar industry: Royal Dutch/Shell, BP and Total. They find that oil companies have been early movers in the solar market but their success in exploiting the new business has been limited. They argue that the slow development

of incumbent's solar energy activities may be explained by the rather disruptive nature of solar photovoltaic technology (Bower and Christensen, 1995), which does not fit an oil firm's main-stream business model. The successful exploitation of market opportunities in this field requires the development of new competences and resources compared to those traditionally held by oil and gas firms (Kolk and Pinkse, 2008). Misfit with the existing business model has led two of the three investigated companies to establish separate business units, but those did not succeed to keep up with the fast growth of specialized solar companies. Therefore, Pinkse and Van den Buuse predict that oil and gas firms might abandon solar photovoltaic investments, and instead focus on developing and commercializing those renewable energy technologies, which can be more easily integrated in their supply chain, as for example biofuels. In terms of policy implications, their pessimistic assessment about the ability of incumbents to compete in the emerging solar market raises an important question: Should policies be designed to provide incentives for established industry players to invest in solar, or would scarce resources be more productively directed towards new entrants and entrepreneurial firms? While the authors provide clear evidence for the shortcomings of incumbents' attempts to enter the solar market, they also point to the worrisome trend of a "recarbonization" of the oil and gas firms. Therefore, simply moving policy attention away from "Goliaths" and towards "Davids" may not be the answer—perhaps calling for an "ambidextrous policy" approach as suggested by Hockerts and Wüstenhagen (2010, p. 490), in which a combination of tailor-made policies simultaneously address the "greening" of incumbents and support the emergence of new entrepreneurial competitors.

Loock (this issue) reports on the results of explorative choice experiments with a set of renewable energy investors. He investigates the relative importance of traditional financial metrics (like price/earnings ratio) vs. qualitative factors in explaining the decision to invest in renewable energy firms. In his stated preference dataset, he finds support for the hypothesis that in this emerging industry, qualitative factors – and notably a firm's business model (Chesbrough and Rosenbloom, 2002; Magretta, 2002; Morris et al., 2005; Zott and Amit, 2007, 2008) – play a more prominent role than the price/earnings ratio. Among three generic business models, the surveyed investors preferred a "customer intimacy" business model that proposes best services over business models that build on the lowest price or the best technology. Although limited by the small sample size, this paper provides a fresh perspective on empirically investigating investor preferences and decision-making. While using stated preference

data and choice-based conjoint analysis is an unusual methodological approach in mainstream finance, the community's preference for working with large ex-post datasets may prevent it from systematically investigating emerging industries like renewable energy, where such datasets are not readily available. Loock's paper therefore may inspire future research using business model attributes to predict the performance of renewable energy firms, an approach that seems to be widely used by investment practitioners.

Masini and Menichetti (this issue) examine the decision-making process underlying investments in renewable energy technologies. The authors propose and test a conceptual model that examines behavioral factors affecting investment decisions, as well as the relationship between renewable energy investments and portfolio performance. Based on a hand-collected dataset of European investors, they study how investors' a priori beliefs, their preferences for certain policy instruments and their attitude towards technological risk affect the likelihood of investing in renewable energy projects. They also find that portfolio performance increases with an increase of the renewable energy share in the portfolio, which raises an interesting question about a possible underperformance of investors whose policy- and technology-related beliefs prevent them from investing in renewable energy. Implications for scholars, investors, technology managers and policy makers are discussed.

4.2. Empirical approaches to assess the cost of capital for renewable energy investment

Sadorsky (this issue) investigates the determinants of systematic risk (beta) for renewable energy companies. He finds that risk is indeed very high for renewable energy firms, and is largely a factor of two determinants, namely sales growth and oil price changes. Renewable energy company risk increases with rising oil prices, and decreases with sales growth. Other factors included in the variable beta model, namely debt to equity, firm size and R&D expenditures, do not have a statistically significant impact on beta. The model is tested with a sample of 52 renewable energy companies included in the Wilderhill Clean Energy exchange-traded fund (ETF), which has been traded since 2005. In terms of policy implications, Sadorsky concludes that – because it is inherently difficult to manage oil price risk – governments should try to mitigate renewable energy company risk by contributing to sales growth, either directly in the form of green procurement strategies, or indirectly through market creation policies such as feed-in tariffs.

Donovan and Nuñez (this issue) take the theme of estimating beta and investigating the cost of equity capital for renewable energy firms to emerging economies, notably Brazil, China and India. They adopt an empirical research design, testing a set of different asset pricing models for their robustness in estimating the cost of capital. The selected sample consists of all the publicly listed companies belonging to the renewable energy industry in the Brazilian, Chinese and Indian stock markets. Overall, 60 companies are analyzed. Their results suggest that renewable energy portfolios in these countries present average or below-average risk to investors. In particular, the renewable energy industry in Brazil is found to have a lower risk profile than the average industry in the Brazilian economy, while the renewable energy industry in China and India exhibit average levels of risk. The paper is policy relevant in that it may help policy makers to – as the title suggests – “figure what's fair”, i.e. determine country-specific hurdle rates below which a renewable energy investment would qualify as additional under the Clean Development Mechanism (CDM).

4.3. Portfolio analysis of renewable energy investment

Fuss et al. (in press) look at the adoption of renewable energy and carbon mitigation technologies in the current situation of climate change negotiations and unclear regulatory framework. In this respect, they analyze the impact of uncertainty on renewable energy and low carbon technologies investment decision-making at plant level. A real-option valuation model is used to optimize operational and investment decisions for one plant at a time, which provides the cost or return distributions resulting from optimal behavior at the plant level. These distributions then enter a portfolio selection problem, which minimizes risk subject to a constraint on cost or return or optimizes cost or return subject to a constraint on risk. Using the GGI scenarios developed at the International Institute for Applied System Analysis within their Greenhouse Gas Initiative (IIASA, 2009), the authors assess the effects of the various sources of uncertainty and identify different portfolios that are robust across different scenarios, differing in terms of emission reduction targets to be adopted, socio-economic developments over the next decades, technology development and volatility of prices.

Bhattacharya and Kojima (this issue) apply the portfolio optimization concepts to demonstrate the scope of greater utilization of renewable energy while reducing the embedded investment risk in the conventional electricity sector and its related financial burden. Japan serves as an empirical context for their research, which has been conducted before the 2011 Fukushima nuclear accident, and yet providing relevant insights today. Among OECD countries, Japan has one of the highest degrees of reliance on energy imports, and is therefore exposed to security of supply risks. Bhattacharya and Kojima's paper demonstrates that increasing the level of renewable energy investments can lower the risks of the energy supply portfolio, by mitigating the volatility of fossil fuel prices, as well as capital, operating and carbon costs. Specifically, their findings suggest that a risk-minimizing Japanese electricity supply portfolio would be characterized by 9% of new renewable energy sources, as opposed to the current share of about 1%. Their recommendation that investors should shift their focus from cost minimization to a more balanced view of risk-return optimization could hardly be more topical in today's context.

4.4. Renewable energy investment in the south: Carbon market risk, political risk and the World Bank's role

Four of the papers in this special issue focus on aspects of renewable energy investment in developing or emerging economies. Two of them investigate the role of the Clean Development Mechanism (CDM) and the associated carbon market risk for renewable energy investment. Zavodov (this issue) focuses on the determination of an optimal price for carbon in the primary market as a prerequisite to stimulate increased investment in the sector. The author develops and applies a cooperative option game model for pricing primary carbon under fixed and variable compensatory structures. The model is tested against two datasets for primary market data, in order to check whether any systematic deviations from the model-implied results can be observed in the prices of certified emission reductions (CERs). The results suggest that indeed the observed prices systematically deviate from the cooperative option model-implied prices, and that the sign of the deviation indicates that the observed prices have been consistently higher than the model-implied estimates. Findings further suggest that deviations are to be explained by the fact that volatility is underestimated in primary market transactions. The tests further suggest that carbon firms may have been too optimistic about the volume of carbon shortage in the

compliance markets and the opportunity and costs of waiting to invest in CDM projects due to their scarcity. This points to the fact that carbon market may have been driven more by speculations rather than fundamentals and thus it appears questionable whether the CDM alone will provide adequate support for renewable energy investments in the long run.

Hultman et al. (this issue) take a different methodological approach to investigating CDM markets, and look at the perceived risks and benefits of undertaking CDM investments in Brazil and India. They use a comparative case study approach, conducting firm-level interviews in both countries in the cement and sugar industry over a five-year timeframe. Results indicate that managers engaging with international carbon markets often do not necessarily account for financial benefits systematically. Secondly, they sometimes consider non-financial factors as their primary motivation. Finally, under fluctuating regulatory regimes with real immediate costs and uncertain future revenue streams, they favor projects that are non-additional or only marginally additional. The authors conclude that an eventual negotiated compromise could benefit from more widespread deployment of a sectorally based approach with an effort to retain the project-based system's strengths in institutional and human capacity building. The authors recommend that future iterations of CDM and developments of the United Nations Framework Convention on Climate Change (UNFCCC) Executive Board regulations should reconsider their goals for strict additionality and their mechanisms for achieving it.

Moving from Brazil and India to renewable energy investment in the North African and Middle East (MENA) region, Komendantova et al. (this issue) conducted qualitative expert interviews to investigate the main risks perceived by European project developers that could influence the deployment of concentrated solar power (CSP). In their research, conducted before the Arab Spring started to unfold in the region in 2011, they found that three types of risk are of particular concern to investors, namely regulatory risk (including corruption and complex bureaucratic procedures), political risk (including general political instability if it is a country) and *force majeure* risks (including terrorism). Other risks, such as technical, construction, operation, financial and environmental risks, were seen as relatively less important. The authors conclude that mitigating regulatory risk and providing stable and predictable policy frameworks are key prerequisites to attract renewable energy investment for large-scale renewable energy projects in the North African region like Desertec.

Finally, based on two case studies of solar lighting in South Asia, Wong (this issue) explores the effectiveness of the World Bank's investment strategies in renewable energy. He derives three design principles for the Bank's interventions, namely cost-effectiveness ("getting the prices right"), good governance ("getting the institutions right") and appropriate technology ("getting the context right"), and compares the performance of the two solar lighting cases against the Bank's own objectives. As a result, he identifies significant shortcomings of current programmes in all three dimensions: financial exclusion, weak governance and a low level of customer and NGO participation. Wong suggests that facilitating access to credit financing, establishing a robust customer feedback system and developing strategic partnerships with non-governmental organizations would help the World Bank improve its renewable energy financing programmes in South Asia. Overall, his paper argues that careful contextualization is a key prerequisite for successful renewable energy investment strategies in developing countries.

5. Further research

The contributions in this interdisciplinary special issue of Energy Policy illustrate that the topic of strategic choices for

renewable energy investment is highly relevant and well worth studying, but at the same time we are left with a number of fascinating avenues for further research.

First, there is a recurring theme of understanding appropriate measures for risk, return and the resulting cost of capital for renewable energy investments across different geographies and asset classes. As shown by the papers of Sadorsky (this issue) and Donovan and Nuñez (this issue), renewable energy investments can be either more or less risky than other asset classes in different countries, and it is all but evident what a fair hurdle rate is. Moreover, those studies demonstrate that investment risk in the renewable energy sector can indeed be quantified, but measures are highly influenced by assumptions, both input assumptions to the asset pricing model and, systematically, the assumptions that support the economic logic of the model itself (e.g. CAPM). One conclusion then is that policy makers should become more familiar with the tools that investors use to set the cost of capital for renewable energy investments, but those papers also identify the limitations of using a purely rational framework to understand strategic investment decision-making in this sector. On a methodological level, the findings of these early studies are limited by a relatively short history of renewable energy investments. Future research can benefit from improved data availability due to the maturing nature of the renewable energy industry, and explore the suitability of different asset pricing models in explaining firm and industry betas.

Second, apart from understanding risk and return on the firm or project level, the contributions by Fuss et al. (in press) and Bhattacharya and Kojima, this issue, as well as earlier work by Awerbuch (2004) and others, highlight the importance of portfolio effects. Future research should further investigate the usefulness of portfolio theory to assess the value of renewables in energy systems, for example as a means to reduce fuel price risk. A topical issue could also be to investigate how the decision of some governments to phase out nuclear energy after the Fukushima accident in 2011 influences the composition of the optimal power generation portfolio, and what the implications are for investment in different renewable energy technologies.

A third area for further research is to further investigate the idea of investor segmentation as a starting point for developing "tailor-made" policies. Given the heterogeneity of investors along the innovation chain (Fig. 3) as well as with regard to other dimensions like firm size (incumbents vs. entrepreneurial new entrants) and geography (industrialized vs. developing countries), more empirical research is needed to explore which policies work well across the entire spectrum, and which ones may be effective for one segment of investors but not for another, both with regard to investor attitudes as well as actual investment behavior.

Moving from the world of "rational" finance into behavioral approaches, a number of contributions in this issue have started to shed light on real-world decision processes of investors under bounded rationality—a theme that seems worth further exploration. Further research in this area could take one of two philosophical approaches: it could either try to detect cognitive biases and follow the tradition of behavioral economists to "prove irrationality", as for example in the case of status-quo bias. Alternatively, it could follow the approach of scholars in the heuristics and intuitive decision-making camp, which would argue that rationality is a relative term, and if actual investor behavior deviates from the predictions of textbook economics, this may not be an indication of a lack of rationality, but rather a mis-specification of such rationality on behalf of the researcher. An example would be Goldstein and Gigerenzer's (2009) work demonstrating that simple rules of thumb ("fast and frugal heuristics") often work just as well as more complex decision procedures, especially in the context of limited information and

limited processing time—arguably two conditions that are not unknown in the context of a newly emerging industry such as renewable energy.

Whatever the philosophical approach pursued, a bounded rationality perspective could shed light on the role of cognitive aspects shaping risk perceptions and return expectations. What are the cognitive processes that lead some investors to perceive investment opportunities in renewable energy as too risky, whereas others evaluate the same opportunity as attractive, as in the case of oil industry incumbents vs. other new entrants to the solar industry? What are the determinants of path dependence in energy investments? Can for example prior investment, group dynamics, organizational culture or network effects explain observed patterns of investment better than pure risk-return considerations? Are risk-assessment tools and return metrics that have been used to judge conventional energy projects appropriately capturing the costs and benefits of renewable energies? And once this has been explored, how can policy build on this knowledge to devise more effective regulatory frameworks in an evolutionary and boundedly rational world? What is, for example, the relative importance of “symbolic” policies compared to the actual monetary value of incentives? Interdisciplinary collaboration between scholars in political science, finance, marketing and economic psychology may be useful to come up with new insights here, although there are obviously limits as to how far investor preferences can form an adequate basis for long-term policy making.

Given this wide array of possible areas for further research on strategic choices for renewable energy investment, we hope that readers will find the collection of papers in this special issue an inspiring starting point to embark on research at the intersection of energy policy, finance and behavioral sciences. We are confident that this will provide valuable further insights in how to reach the substantial investment levels needed to successfully manage the transition into a renewable energy future.

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