WORKING PAPER SERIES

Green Finance: Recent developments, characteristics and important actors

Andreas Welling

Working Paper No. 2/2017

OTTO VON GUERICKE
UNIVERSITÄT
MAGDEBURG

FACULTY OF ECONOMICS
AND MANAGEMENT

Impressum (§ 5 TMG)

Herausgeber:
Otto-von-Guericke-Universität Magdeburg
Fakultät für Wirtschaftswissenschaft
Der Dekan

Verantwortlich für diese Ausgabe:
Andreas Welling
Otto-von-Guericke-Universität Magdeburg
Fakultät für Wirtschaftswissenschaft
Postfach 4120
39016 Magdeburg
Germany

http://www.fww.ovgu.de/femm

Bezug über den Herausgeber
ISSN 1615-4274

Green Finance: Recent developments, characteristics and important actors

Andreas Welling

Faculty of Economics and Management, Otto-von-Guericke University
Magdeburg, Germany

Abstract:

Various so-called green investments are intended to limit the warming of the earth's climate, thus minimizing social, environmental and economic damage. The article introduces into the corresponding research field of Green Finance by providing current data, by showing historical developments, and by forecasting future tasks. Further, the article depicts the major difficulties of research on Green Finance; particularly rapid technological progress, the dependence of governmental support, high uncertainties, and, especially the interactions of so many actors. Finally, the article gives a short review on the research field of Green Finance.

* Corresponding author, Faculty of Economics and Management, Chair in Financial Management and Innovation Finance, Otto-von-Guericke-University Magdeburg, Universitätsplatz 2, D-39106 Magdeburg, Tel: +49 (0) 391 67 - 50169; Fax: +49 (0) 391 67 - 480 07, e-mail address: andreas.welling@ovgu.de

1. Introduction

Up to today, no commonly accepted definition of the term “Green Finance” exists (see Lindenberg, 2014). Instead, its meaning is varying significantly between various publications. Following Eyraud et al. (2011) we will understand Green Finance as a broad term that *“refers to the investment necessary to reduce greenhouse gas and air pollutant emissions, without significantly reducing the production and consumption of non-energy goods*”. According to the Stern Review on the Economics of Climate Change (Stern, 2007), without action, the climate change can result in a monetary-loss of more than 5% of worldwide GDP. Additionally, the climate change is expected to lead to terrible non-monetary effects like a high death toll, the need of migration, the loss of habitat or the extinction of species. However, by a crucial reduction of the world wide carbon emissions these catastrophic consequences can still be prevented. Here, green investments are vital as they reduce carbon emissions (i) by providing low-emission energy supply, (ii) by increasing energy-efficiency, and (iii) by sequestration of carbon (see Figure 1).

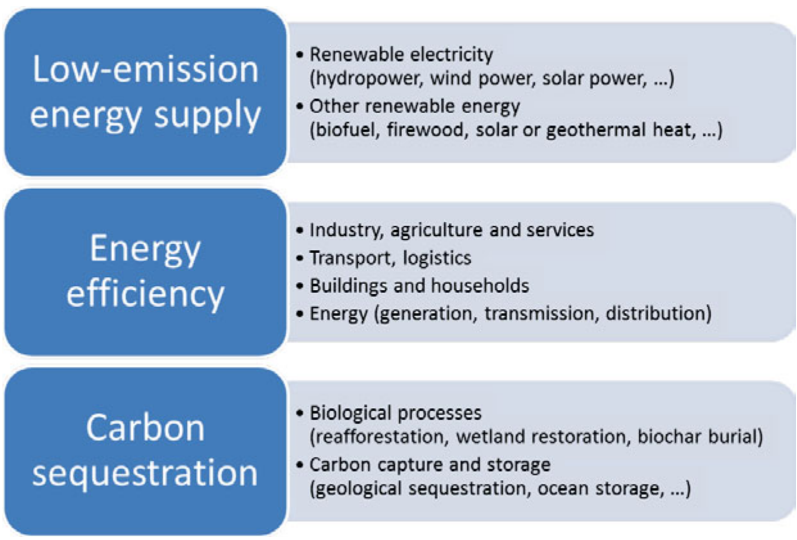

Figure 1: Overview on green investments (based on Eyraud et al., 2011)

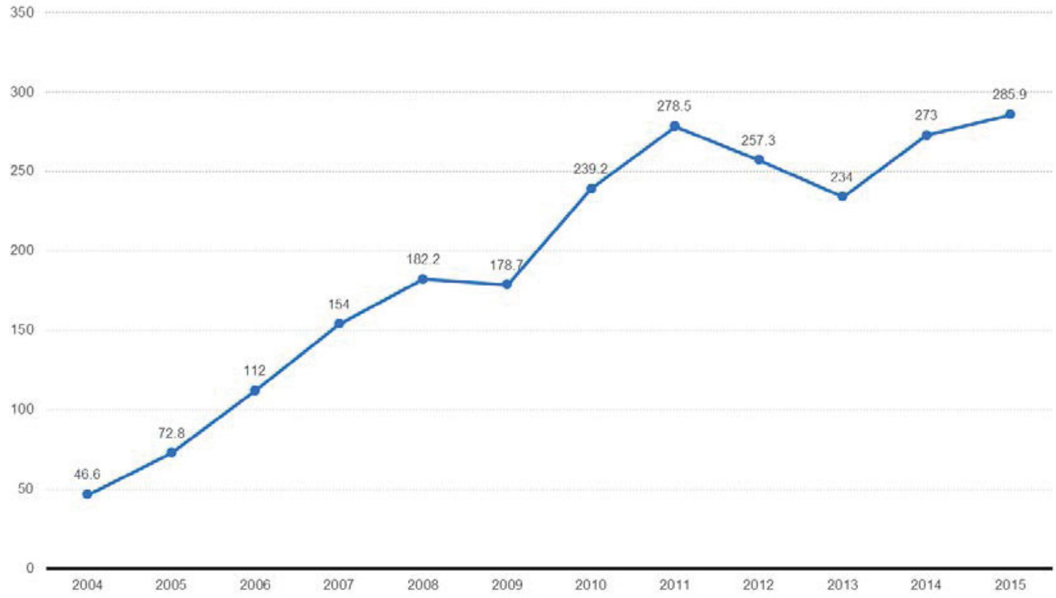

Figure 2: Development of worldwide renewable energy investments between 2004 and 2015 in billions of US-Dollars (Sources: UNEP; Bloomberg New Energy Finance, statista.de).

The total amount of worldwide green investments can hardly be estimated. Especially, energy efficiency investments usually are not particularly counted and are often difficult to distinguish from replacements. For example, did a certain company buy a new machine because the old machine was broken and had to be replaced? Or because technological change required a new machine? Or because it just wanted to increase its production capacity? Or because the new machine is more energy-efficient and safes energy costs? Only in the latter case, buying the machine is undoubtedly an energy-efficiency investment. In reality, usually a mixture of the four different motivations induces the investment.

Though, the total amount of energy-efficiency investments cannot exactly be measured; only some estimations or predictions on the amount of worldwide energy-efficiency spending exist. For example, it has been estimated that in 2013 worldwide 825 billion US-$ have been spent for clear energy-efficiency investments. Consequently, almost surely, energy-efficiency investments have the highest market volume of all Green Investments.

However, in case of renewable energy investments sufficiently reliable data exists to measure the worldwide investment activity. In particular, between 2004 and 2015 the annual worldwide renewable energy investments have increased from 46.6 billion US-$ to 285.9 billion US-$ (see Figure 2). For comparison, in the same time only 20 billion US-$ have been invested in carbon sequestration projects.[1] Consequently, we will in the following focus on renewable energy investments. With the exemption of the years 2009, 2012 and 2013 an increase in the annual renewable energy investments can be observed in any year. In total, more than 2.3 trillion US-$ have been invested in renewable energy projects during the last 12 years. As a consequence the production of renewable energy has increased from 1,037 Gigawatt in 2006 to 1,935 Gigawatt in 2015.[2] Though, the worldwide share of renewable energy on the total produced primary energy has only increased slowly since 2006. In 2006 renewables had a share of 12.4% on total primary energy production. 2015 this share has been 13.5%.[3]

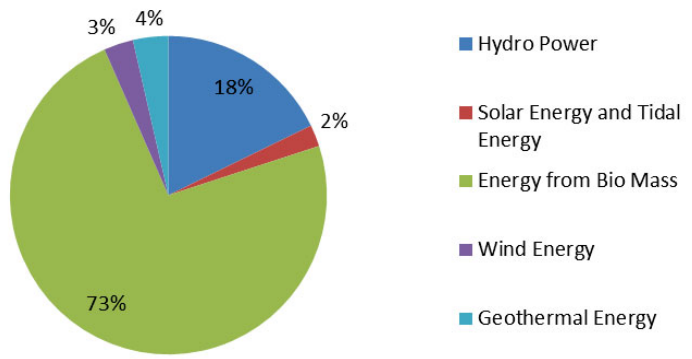

Figure 3: Share of different renewable energy sources on the worldwide total production of primary renewable energy in 2013 (Sources, IEA, statista.de).

[1] International Energy Agency (2015), Tracking Clean Energy Progress 2015, OECD/IEA, Paris
[2] Statista.de, retrieved July 11th, 2016
[3] Statista.de, retrieved July 11th, 2016

A clear majority of the worldwide renewable energy is produced from bio mass (73%); mostly fire wood and bio-fuels, but it also includes electricity from burning waste or energy crops (see Figure 3). Another larger proportion comes from hydro power sources (18%). Wind energy, solar energy, geothermal energy, and tidal energy count for only 10% of the world's renewable energy production. Interestingly, with regard to renewable energy investments wind power and solar power are dominating. In particular, from the 285.9 billion US-$ that have been spent into renewable energy in 2015, 161 billion US-$ (56.3%) have been invested into solar energy and 109.6 billion US-$ (38.3%) have been invested into wind energy.[4] Furthermore, in 2015, 81 billion US-$ (28.3% of the worldwide renewable energy investments) have been invested in China, followed by the United States with 36.3 billion US-$ (12.7%), Japan with 34.3 billion US-$ (12%), the United Kingdom with 13.9 billion US-$ (4.9%), and Germany with 11.4 billion US-$ (4.5%) (see Figure 4).

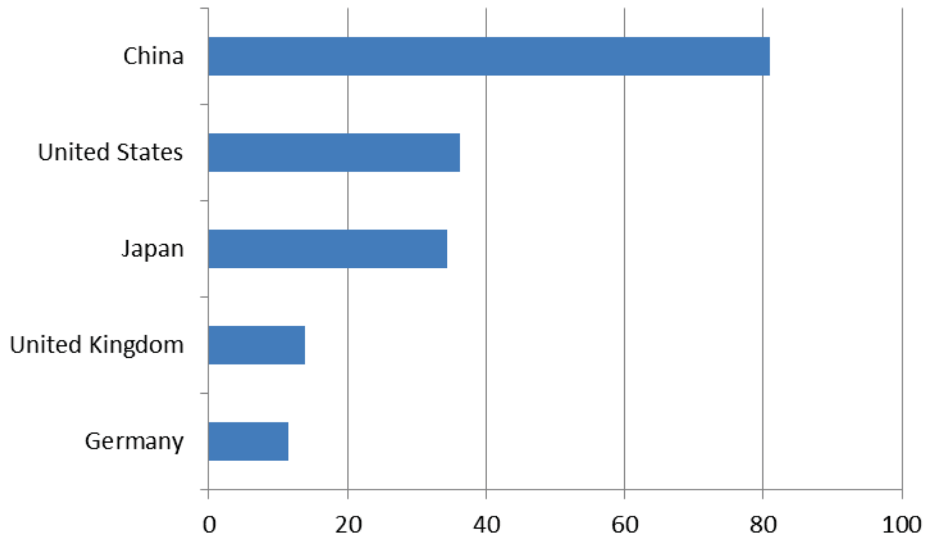

Figure 4: Most important countries in the world according to their level of investments in renewable energy in 2015 in billions of US dollars (Source: Bloomberg New Energy Finance).

[4] UNEP, Bloomberg New Energy Finance, statista.de, retrieved July 11thg, 2016

Thus, undoubtedly, Green Investments have an impressive volume and investors, manufacturers and governments should be interested in their dynamic development. However, it is not the market size that justifies a separate consideration to other investment opportunities. Instead, green investments show unique characteristics that differ from common investments.

The most important of these differences are big importance of externalities, dependence on governmental support, rapid technological progress and multiple sources of uncertainty. They will be discussed in detail in chapter 2. In Section 3 the view of five key-actors with respect to the diffusion of green technologies is explained; particularly investors, manufacturers, infrastructure operators, governments, and researchers. Furthermore, the interdependencies of these actors and influences from additional actors are shown. Section 4 gives a short review on research in the field of Green Finance. Finally, Section 5 concludes and gives perspectives for future research.

2. Characteristics of Green Investments

Green investments differ from common “non-green” investments by four special characteristics; they cause externalities, their profitability depends on governmental support, they occur in an environment of rapid technological progress and they are subject to severe uncertainties. Obviously, not every green investment project necessarily has to cope with every of these four characteristics. Likewise, also non-green investments may cause externalities, may depend on governmental support, may occur in an environment of rapid technological progress, or their profitability is uncertain.

2.1 Externalities of Green Investments

Green investments create a multitude of externalities. First of all, they help to prevent the climate change and its consequences. But green investments can also have strategic benefits. Increasing energy efficiency and the production of renewable electricity both reduce the dependence of a country from oil or gas exporting countries (Tänzler et al., 2007). Simultaneously, the trade balance of the respective countries is improved - at least as long as a substantial part of the value added is created domestically. From an economic viewpoint, all kinds of green investments create jobs, resulting in a higher GDP as well as higher taxes and social security contributions. For example, only the production of renewable electricity is assumed to have created 370.000 jobs in Germany (O'Sullivan et al., 2015). On a worldwide basis it is even estimated that green investments create fifteen to sixty million jobs (Poschen and Tobin, 2012). Furthermore, technological progress is enhanced by green investments, improving the market opportunities of the country's industry on the world market.

However, green investments also cause negative externalities. Increasing energy efficiency by thermal insulation can increase the risk of fire and in a case of fire result in toxic vapors.[5] According to Schuiling (2014) carbon capturing and sequestration is not safe and not sustainable. On one hand the process of capturing and storing carbon needs a substantial amount of energy and thus produces extra carbon. On the other hand a high risk exists that a carbon leakage might harm the health of people nearby or the surrounding environment. Furthermore, a carbon

[5] Spiegel Online, November 5th, 2014: „Behörden-Tests: Dämmung an Millionen Häusern kann Brände anfachen".

leakage revokes the benefits of the carbon capturing. Regarding renewable energy it is often argued that the production of bio-fuel competes with the production of food and thus starves the poorest (Ford Runge and Senauer, 2007). Furthermore, it is argued that for the production of bio-fuels often valuable natural areas, for example tropical rain forests, have to be destroyed (Fitzherbert et al., 2008). With regard to renewable electricity, the construction of dams for hydro power certainly has a weighty impact on nature and landscape. Likewise, wind power is blamed for noise, disturbing shadows, the death of bats and birds as well as for negative landscape externalities (Meyerhoff et al., 2010). Finally, the massive production of renewable electricity provides great challenges to utilities and network operators. Due to the volatile electricity production, especially in case of wind power and photovoltaic, the requirements for the net infrastructure and very flexible conventional power plants increase. For this reason, a considerable investment effort is required to ensure permanent supply. In Germany, according to the Bundesverband der Energie- und Wasserwirtschaft, investments of more than fifty billion Euro will be needed for the net infrastructure until 2032.[6]

However, in many cases the most important deficiency of green investments is that they are not profitable to investor's on a stand-alone basis. For example, in the case of renewable electricity, the levelized costs of electricity determine whether a certain electricity source is competitive to the market. For each electricity source this levelized costs of electricity can be determined by dividing the sum of costs over life-time of the electricity producing system by the sum of electricity produced over the life-time of the electricity producing system. As can be seen in Figure 5, in Germany as well as in the US, renewable electricity from

[6] Der Tagesspiegel: "Die Angst vor dem Staat". 8.6.2016

offshore wind power, photovoltaic, and bio mass is not yet competitive to conventional electricity sources like coal, natural gas or IGCC or lignite. Onshore wind power, thus, is the only renewable electricity source that has already reached competitiveness. According to Allcott and Greenstone (2012) most professionals in the energy industry have long believed in an enormous “win-win” opportunity of energy efficiency projects, i.e. saving money and reducing the energy use at the same time. However, due to imperfect information companies and households often do not undertake energy efficiency investments, which would profitable to them. Thus, the energy efficiency gap is created, “a wedge between the cost-minimizing level of energy efficiency and the level actually realized”. Finally, carbon sequestration does not create any surplus on a standalone basis.

2.2 Governmental Support of Green Investments

Usually, the positive externalities of green investments are seen to far outweigh the negative externalities. Thus, in the cases, where green investments are not profitable on a standalone basis, governmental support is needed to generate these investments. The different possibilities of promoting green investments can be categorized in subsidies, regulation, pricing, or quotas and caps (see Figure 6).

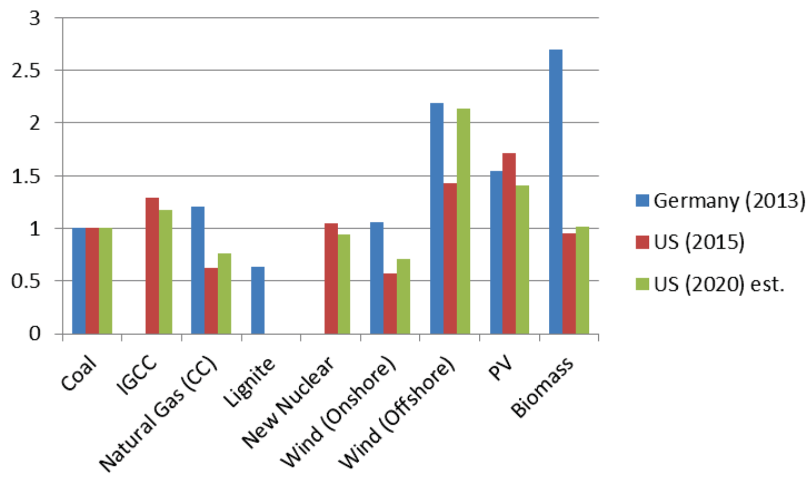

Figure 5: Levelized costs of electricity for different electricity sources. Index value, based on the electricity costs from coal in the respective study. Blue: costs in Germany 2013, determined by the Fraunhofer Institute for Solar Energy Systems (Kost et al., 2013); red: costs in the United States 2015, determined by the U.S. Energy Information Administration in 2015; green: costs in the United States 2020, estimated in by the U.S. Energy Information Administration in 2015.[7]

Fiscal instruments, e.g. subsidies or tax incentives, use government funds to increase the profitability of green investments by decreasing investment costs and/or increasing profits. They are easy to understand and implement, however, they are not necessarily cost effective and it is not guaranteed that a certain target is met (Gan et al., 2007). An example are tax deductions and credits of the US government for producers of renewable electricity (Gan et al., 2007). Another example are subsidies on the investment costs and subsidized financing of energy efficiency investments, e.g. thermal insulation by the German government (Galvin, 2010).

[7] U.S. Energy Information Administration: "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2015"

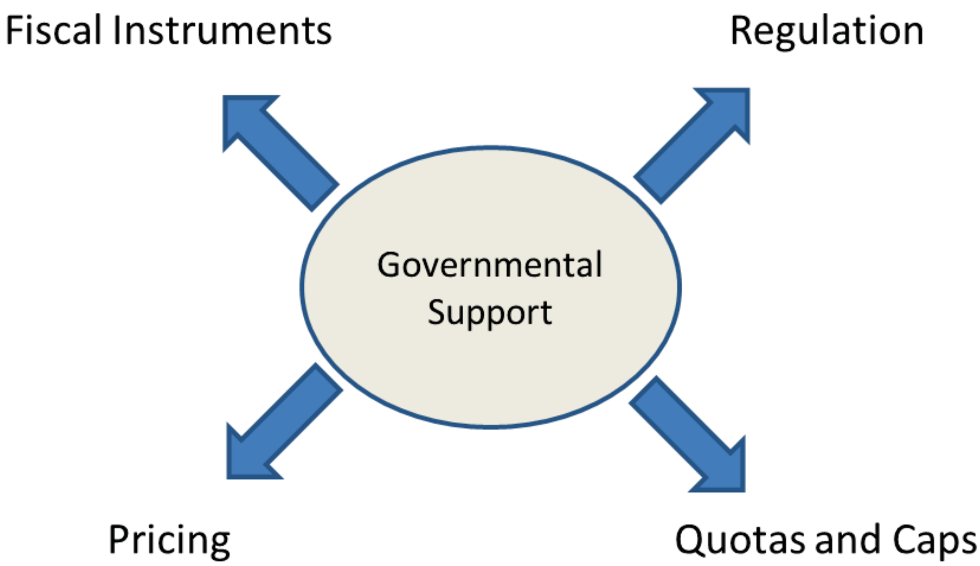

Figure 6: The four fundamental ways of governmental support of green investments

By using regulation to promote green investments, governments assure by law that investors do not have another choice but to invest in projects with a minimum "greenness". By regulation a government can be sure to meet a certain target. However, regulations are usually not cost-effective. Examples are the German "Energieeinsparverordnung für Gebäude" that establishes a maximal heat energy consumption per unit floor area for new constructed buildings (Galvin, 2010) or the European Union's mandatory emissions target for new cars of 130g/km that will be reduced to 95g/km in 2021.[8] Furthermore, many countries have endorsed mandatory blending targets of bio-fuels. For example, in Canada gasoline has to contain at least 5% bio-fuels, the same holds for Argentina and several Indian states. Beginning in 2020 even a ten percent bio-fuel share is mandatory in the European Union (Sorda et al., 2010).

[8] International Council on Clean Transportation: „EU CO_2 emission standards for passenger cars and light-commercial vehicles", 2014.

By using quotas and caps to support green investments a government relies on market mechanism for resource utilization and technology choice (Gan et al., 2007). Here, a government defines a certain quota (minimal share) or a cap (maximal amount) every company within a certain industry or several industries as a whole have to achieve. Companies that do not perform according to the quota or cap have to buy certificates. Companies that perform better than the quota or the cap gain certificates, they can sell. Obviously, by using quotas and caps a government can achieve any target with security. However, transaction costs of quotas and caps are high. Furthermore, quotas and caps do not support high cost technologies that due to learning effects might become profitable in the future (Gan et al., 2007). An example of a cap system is the European Union Emissions Trading Scheme for carbon, where the European Union establishes a certain cap for the combined carbon emission of several European industries. For each ton of carbon a company of any of these industries emits, it has to hand over a carbon certificate. An example for a quota is the renewable portfolio standard in the state of New York which in 2015 mandates utility companies to feed at least 29% renewables into the grid. [9] The quota can either fulfilled by the utility company themselves or buy the acquisition of renewable certificates.

Pricing is mostly used in the case of supporting renewable electricity. Here, the government implements a system that allows producers of renewable electricity to gain a higher price per kWh than the market price. Today, three different mechanisms are used to support renewable electricity. First, some governments have established feed-in tariffs. Here, producers of renewable electricity have the guarantee to get a fix payment per kWh electricity produced. Feed-in tariffs are

[9] DESIRE, North Carolina State University (www.desire.org, retrieved July15th, 2016).

the most frequently used way of supporting renewable electricity and are used in 65 countries and 27 US-states.[10] Feed-in tariffs provide a save return to investors and can also be implemented via competitive tendering. Furthermore, they easily allow to support different technologies or different investment with different tariffs. However, usually they are not cost-effective and do not ensure to achieve a long-term target (Gan et al., 2007). Second, some governments have established a price-premium support scheme. In a price premium support scheme the government pays producers of renewable electricity a markup on the market price of renewable electricity, either fixed or as a percentage of the market price. In the European Union many original fixed feed-in tariff support systems are at least partly transformed to price-premium support schemes in recent years (Grau, 2014). Price-premium support schemes are more market-based than fixed feed-in tariffs and thus encourage competition between technology generations. Though, they imply a bigger risk to investors (Couture et al., 2010). Third, some governments have implemented net metering. Here, producers of renewable electricity get the chance to virtually use their produced renewable electricity at any time, thus profiting from the difference of the subscription price and the market price of electricity. For example, net metering is implemented in 44 US-sates, Guam and Puerto Rico.[11] Obviously net metering is only appropriate to support small private renewable electricity investments.

Technological progress, economic developments or changes in the green awareness of society sometimes make governments to adjust the support system for certain green investments. For example, in Germany feed-in tariffs for solar

[10] Renewable Energy Policy Network for the 21st century: "Renewables 2012. Global Status Report", 2012.
[11] DESIRE, North Carolina State University (www.desire.org, retrieved July15th, 2016).

electricity are regularly customized to the investment activity in recent periods.[12] Sometimes governments also decide to implement a change in the method of governmental support. For example, the UK has replaced its system of competitive tendering for feed-in tariffs by a quota system (Boomsma et al., 2012). However, the investment activity may be very sensitive to changes in governmental support. In particular, a fundamental reduction in the amount of governmental support or a sudden change in the support system can lead to a total collapse of the investment activity regarding a certain green investment (Haas et al., 2004; Munksgaard and Morthorst, 2008).

2.3 Technological Progress

The overall aim of governmental support of renewables is to initiate a process that brings down the respective costs to a level where these technologies can actually compete with conventional technologies (Kumbaroğlu et al., 2008). And indeed, after massive governmental support, a strong increase in profitability could have been achieved for various green investments during the last decades. For the future a further increase in profitability is expected.

For example, the levelized cost of electricity from wind power has decreased from more than 500 dollar per MWh in the 1970s to less than 50 dollar per MWh in present days. A decisive influence had the technological progress. New design architectures and advanced materials let wind power generating systems get bigger and more powerful. In particular, the height of hubs has increased from 17m in the 1980s to 100m in current days. This allows to access stronger and less

[12] www.bundesnetzagentur.de, retrieved July 6th, 2016.

turbulent winds at higher altitude (Lantz et al., 2012). This trend is expected to continue in the future (see Figure 7).

According to Pillai (2015) a large share in the cost reduction, furthermore, is generated upstream in the supply chain due to learning curve effects. For example, in the case of photovoltaic a price drop in the raw material polysilicon has been caused by increasing plant sizes. Furthermore, solar panels manufacturing prices have been significantly dropped due to the appearance of Chinese manufacturers. Since 1990 the module costs have been decreased from 10 US-$ per Watt to 0.6 US-$ per Watt. This development follows the so called Swanson-Law, i.e. the module price for photovoltaic drops by 20% for every doubling of cumulative shipped outcome (see Figure 8).

As a result the levelized costs of electricity for photovoltaic in Germany have decreased by more than 70% since 2000. Following recent estimations, the levelized cost of electricity for photovoltaic may decrease by further 59% until 2025 (Taylor et al., 2016).

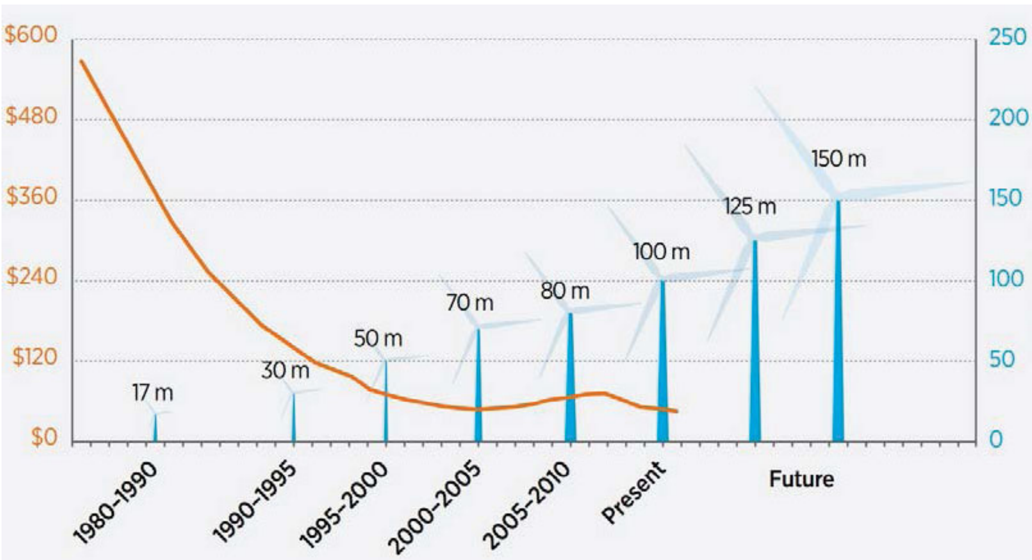

Figure 7: Development of levelized cost of energy for wind power (left) and height of wind power hubs (right). Source: US Department of Energy, DuVivier (2016).

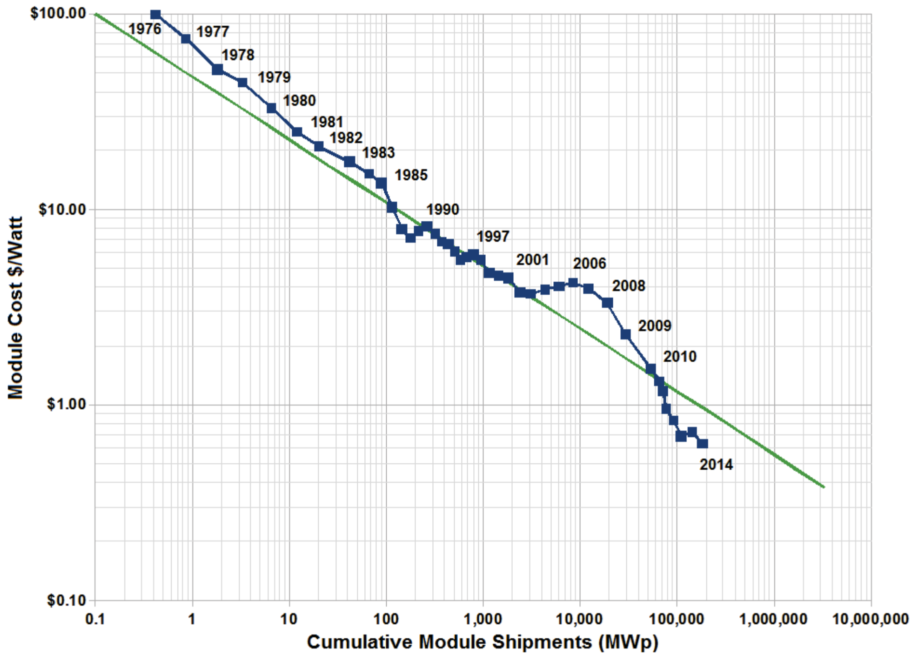

Figure 7: Solar panel module costs per Watt in dependence of cumulative module shipments. Source: wikipedia.de (data from ITRPV Edition 2015).

In case of carbon capture and storage such estimations are difficult to make as projections of the deployment of CCS technologies vary considerably (Koelbl et al., 2014).

2.4 Uncertainties

Green investments are subject to the same uncertainties than ordinary investments. In particular, these are economic uncertainties, political uncertainties and technological uncertainties. However, in case of green investments the extent of these uncertainties as well as their effect usually is much greater.

Regarding economic uncertainty almost all investment projects face uncertainty on wages as well as on other factor prices, uncertainty regarding the (riskless) interest rate and uncertainty about the demand and market price of the produced goods. If we look at the "goods" produced by green investments we observe that many of them are not storable. Unless regulated by statutory rules the price of renewable electricity is continuously determined on the market balancing stochastic demand and supply. Likewise, energy-savings that result from green investments are compensated by the saved market price of electricity. As can be seen in Figure 8 the market price of electricity is extremely volatile. Within one year day-ahead prices may vary between zero and more than 2000 Euro per MWh. Obviously, intra-day prices are even more volatile. Furthermore, prices may even become negative. Likewise, the market price of bio-fuels or of saved conventional fuel also is very volatile, although not nearly as extreme as the market price of electricity.

Consequently, investors in green projects face a high economic uncertainty and can hardly estimate future earnings. This problem is further intensified by the fact that the earnings of most green investments are strongly influenced by political decisions and hence are subject to a great degree of political uncertainty.

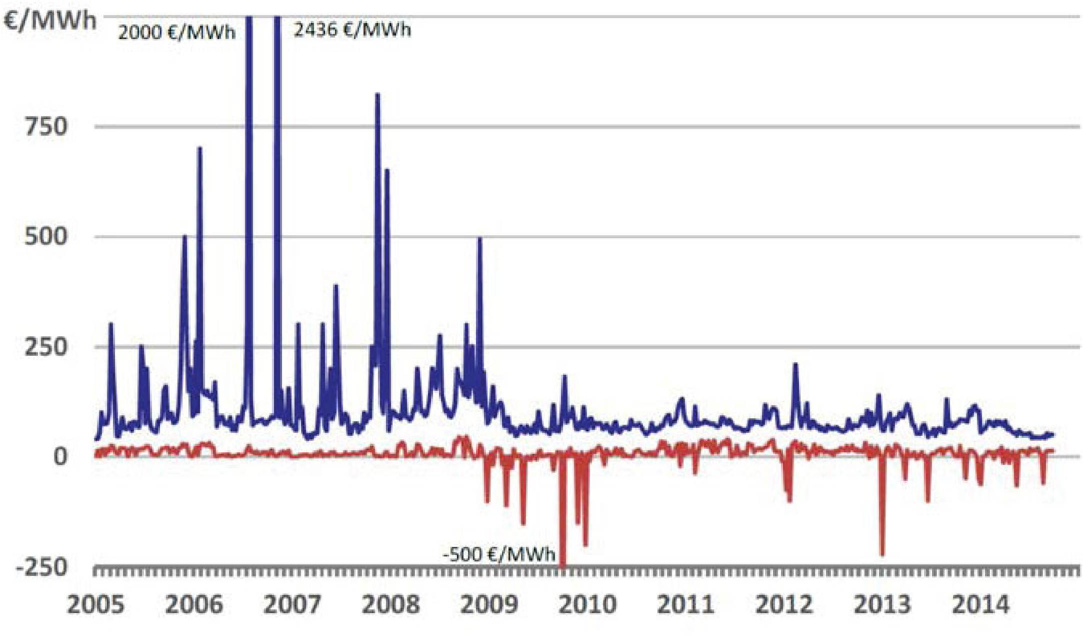

Figure 8: History of price extremes in the German day-ahead market of electricity. Blue: maximum day-ahead price; red: minimum day-ahead price. Source: Fraunhofer ISE, EEX.

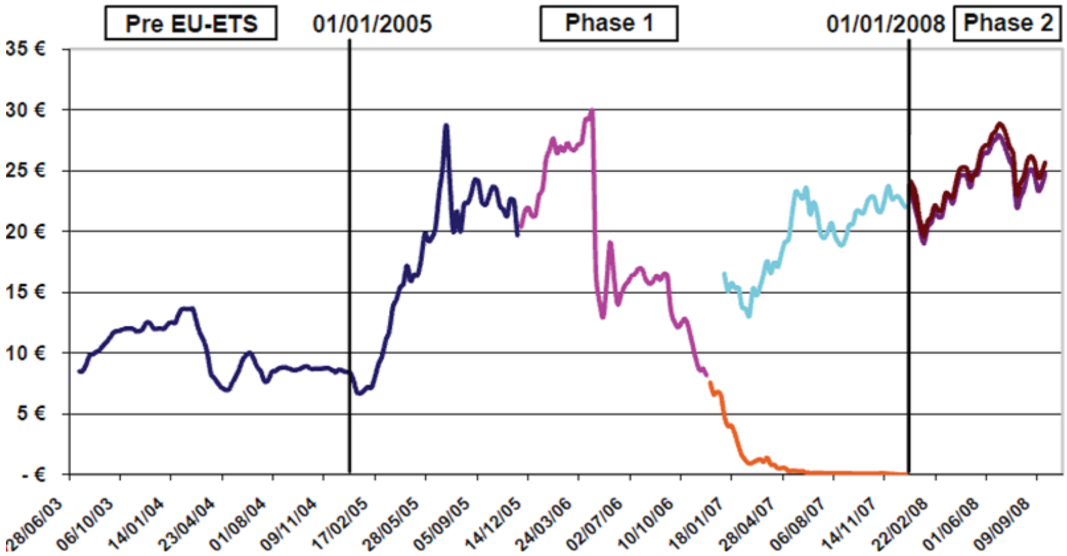

Figure 9: Development of the carbon emission allowances price in Euro per ton CO_2 between 2003 and 2008. Dark blue curve: price between 2003 and 2005; magenta curve: price 2006; orange curve: price 2007; violet curve: price 2008; light blue curve: 2008 future; brown curve 2009 future. Source: Nicole Dellero, AREVA.

For example, the profit of carbon capture and storage depends on two basically political decisions. First, the decision that carbon emissions have to be reduced and, second, the decision about the actual amount of carbon that may be emitted during a certain time span. Especially elections and international summits can result in a major political shift (Kelly et al., 2016), constituting a major risk for the profitability of green investments and carbon capture projects in particular. Figure 9 depicts how much the price of carbon allowances depend on this political decisions. In particular, in the first phase emission allowances were valid until the end of 2007. When it turned out that the quantity of carbon emissions in phase 1 set by the European governments did not exceed the demand for carbon emissions the allowance price fell to zero. However, at the same time allowances of the second phase with validity from 2008 to 2012 had a positive value that could already be observed on the exchange in form of a futures contract.

3. The different actors and their interactions

Green investments take place in an environment characterized by the decisions and interactions of various actors. Particularly, of highest importance are investors, manufacturers, infrastructure operators, governments and researchers (see Figure 10). These main actors all pursue individual goals but are caught in a network of interdependent dependencies. In particular, most decisions of these actors have consequences not only for the own achievement of goals but also for the other actor's possibility to achieve their goals. Sometimes these goals are in harmony. But sometimes they are also mutually contradictory. Additionally, the actors are influenced by further parties (see Figure 10). In the following the roles of the five main actors in the field of green investments will be discussed in detail.

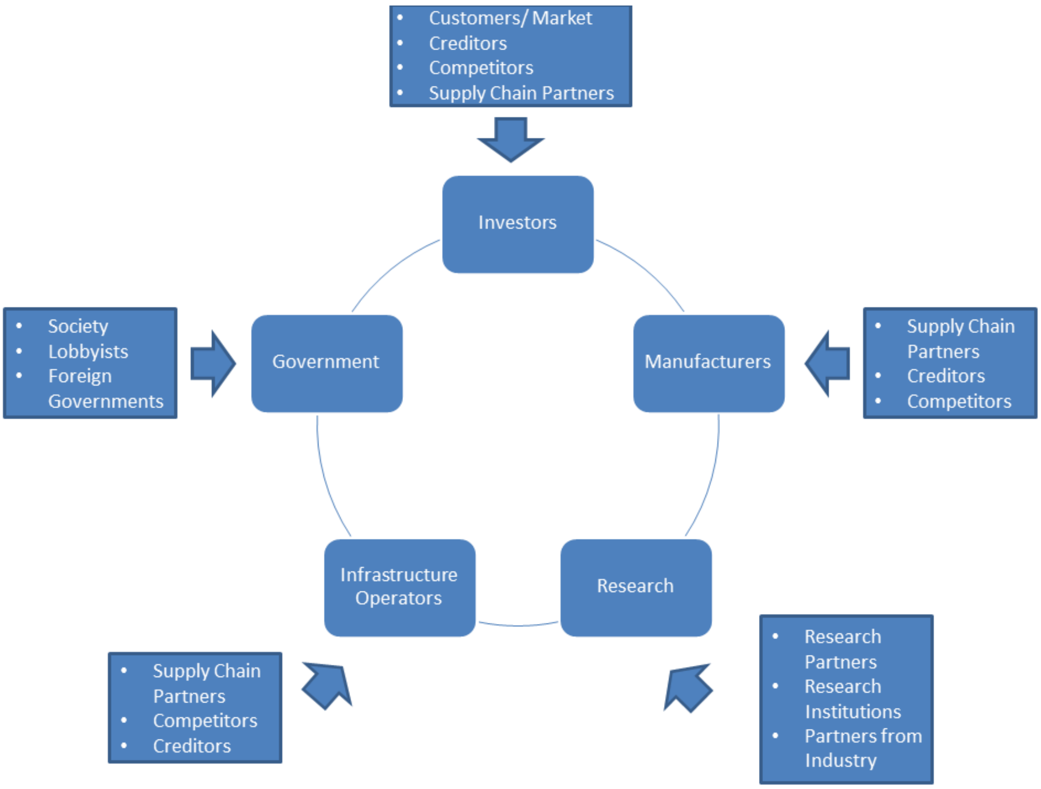

Figure 10: The five most important actors in the environment of green investments and their major influencing groups.

3.1 Investors

According to neo-classical assumptions investors should be rational (homo economicus) and solely aim to maximize their wealth. Hence, they should only select investments according to the risk / return profile. Recently, however, it has been shown that most investors - including institutional ones - pursue further goals including sustainability, whereby the weight on sustainability and the definition of sustainability differs between the investors (Winnett and Lewis, 2000, Lewis, 2001). Thus, if (and when) an investor invests into a green project is partly determined by his individual characteristics.

Obviously, to a great degree the willingness of an investor to invest into a project also depends on the profitability of the project and the associated risk. Both profit and risk are decisively influenced by the actions of other actors. For example, the profitability of carbon capture and storage strongly depends on the future price of carbon emissions allowances (İşlegen and Reichelstein, 2011). These prices, however, are based on political decisions, i.e. the total amount of carbon emission allowances issued, as well as on uncertain economic developments, i.e. the demand of carbon emission allowances. Here technological advantage provided by researchers and its possible implementation by competitors on the same market or of companies at any other market under the same emissions trading scheme plays a major role.

Additionally, investors face the problem, when to invest into a green project. For example, in the case of photovoltaic investments by waiting with the investment the investor can expect to minimize the investment cost. On one hand this may be a result of the hard competition of manufacturers and the expansion of production facilities (economics of scale). On the other hand technological progress done by researchers may make available more efficient technologies. However, by waiting with the investment the investor is exposed to the risk that the government will change the conditions of governmental support for renewables for the bad or that infrastructure operators - net operators in particular - will worsen their terms.

Furthermore, the green investment may depend on the willingness of supply chain partners to engage in a green project. For example, in the case of carbon capture and storage the operator of a coal fired power plant may depend on the cooperation of the operator of an abandoned underground mine, who has to prepare the mine before the storage of carbon can start. Sometimes even the cooperation with competitors is necessary to facilitate a green project. For example, the operators of coal fired power plants who are close to each other may jointly build a pipeline for the removal of captured carbon.

Likewise, the profitability of a green investment depends on the acceptance of customers or their willingness to pay higher prices after the green investment. For example, in the case of investments in energy-efficiency of commercial property Miller et al. (2008) have shown that certified sustainable real estate pays off due to higher occupancy rates compared to conventional real estate and due to customers who are only willing to pay less for conventional real estate. Finally, investors depend on the willingness of creditors to finance their green investment projects. Here, the government again can have an important influence, either by state owned banks or by subsidizing loans for green investments. Furthermore, credit risks to a large extant depend on political risks that can be minimized by the government with the help of grandfathering rules.

3.2 Manufacturers

Manufacturers have an important role in the environment of green investments. Due to economies of scale, i.e. an increasing output, the factory's unit cost can be lowered which allows lower sales prices and hence a higher profitability of green investments. After a certain progress on the learning curve driven by researchers the different manufacturers usually compete on prices - with only few exemptions that provide special solutions for niche markets.

For example, manufacturers of photovoltaic cells may offer different technological solutions to turning sunlight into electricity, however, their customers, i.e. the investors, have no reason to care about the technology if the system generates the promised amount of electricity (Platzer, 2012). For this reason in 2011 and 2012 several German photovoltaic manufacturers had to give up after the market entry of Chinese manufacturers which lead to overcapacities and strongly declining module prices (Bohl et al., 2013). Notably, the price advantage of Chinese manufacturers has not been driven by country specific advantages like lower wages and taxes but it results from much larger scaling and more efficient supply chains (Goodrich et al., 2013).

Hence, it is the main task of manufacturers to increase their efficiency, for example due to capacity expansions, due to improving the collaboration in their supply chain or due to technology adoption. However, the profitability of manufacturers also strongly depends on the demand which is determined by the investment activity of investors in the first instant but also by political decisions and regulation as well as by technological developments of researchers. Thus, to assure profitability, it pays to observe and maybe to influence these other actors.

3.3 Infrastructure Operators

Due to green investments infrastructure operators are facing great difficulties and risks but somehow also new opportunities. For example, with the "Erneuerbare Energien Gesetz (EEG)" of 1991 the German government has made net operators to receive any renewable electricity at any time or otherwise to pay compensation to the producers of renewable electricity. Exemptions can only be made if a grid connection is not necessary or not economically feasible (Hoppmann et al., 2014). The production of renewable energy, however, has a large space requirement and is dependent on wind and sun. While rural regions can become large electricity producers, the urbanized areas cannot meet their own needs. The resulting division of energy production and energy consumption requires an expansion of the electricity grid which is capable of this transfer task.[13] On one hand this means enormous expenditures for net operators on the other hand they may earn high net charges in the future.

From a decision-making point of view infrastructure operators usually have only a reacting role. Decisions are made by the governments and in a second stage by the investors, for example the owners of a wind park. The grid operator then has to act under the given conditions, i.e. he has to maximize its profits under the constraint of guaranteeing grid stability. However, the other actors - especially the governments - should already take into account the skills and problems of infrastructure operators in their own decision-making. For example, problems with the grid expansion can jeopardize the government's objectives. Or even worse, a severe power failure can result in catastrophic problems.

[13] www.herausforderung-netzausbau.de (retrieved January 4th 2017)

3.4 Governments

It is well known that governments and administrations from time to time act for their own benefit. They give their re-election higher priority than the interests of the country or may even be corrupt (Biglaiser and Mezzetti, 1997; Mauro, 1998; Caselli and Morelli, 2004). Furthermore, they are - also in the case of green technologies - continuously influenced by several lobbying groups (Sühlsen and Hisschemöller, 2014). However, even if we assume that governments only act in best interest for the country, they still have to pursue countless goals. In particular, governments have to care about inner security, the military, the economy, social security, education and science, the environment, infrastructure, health care, etc. Consequently, governmental action must always keep an eye on all of these objectives while the weight given to these objectives is represented by the constantly changing social attitudes.

Hence, also governmental programs regarding green technologies are evaluated from different angles; for example the support of renewable electricity production or incentives to increase the energy-efficiency of households (Akella et al., 2009). In addition to the obvious criteria "ecological benefit", "electricity prices" and "cost for tax payers" governments take into account the impact of these programs on employment (O'Sullivan et al., 2015), their impact on foreign and security policy (Tänzler et al., 2007), and the degree of social acceptance (Wüstenhagen et al., 2007). Consequently, governmental decisions regarding the support of green technologies have to be regarded as a multi-criteria decision problem (Konidari and Mavrakis, 2007; Blechinger and Shah, 2011). Moreover, the outcome of the decision depends on the actions of several players and on multiple uncertainties.

Therefore, when designing an optimal policy governments have to take the uncertainties as well as the possible reactions of the other parties into account. In particular, it is important to determine the reaction function of investors, i.e. to which extant will investors invest given a certain support policy. For example, this can be done with the help of investment planning models (Neuhoff et al., 2008). To stimulate green investments governments can also promote the technological progress, i.e. to fund researchers and manufacturers, and maintain the stability of markets (Zhang et al., 2016). Additionally, governments must also take into account the situation of the infrastructure operators in their policy decisions. Here, the "Not in my backyard-problem" has to be solved. In particular, people and local politicians appose infrastructure projects like grid expansions that may harm them but are necessary on a nationwide basis (Dear, 1992; van der Horst, 2007).

Finally, governments are typically not totally free in their policy design with respect to green technologies, but they are bounded by several contracts and treaties with foreign countries. For example, in the 2015 Paris Agreement 195 countries committed themselves to achieve certain individual emission targets (Rogelj et al., 2016). Member states of the European Union furthermore are bound to several European environmental regulations including the European Union Emissions Trading System (EU ETS) and the Effort-Sharing Decision (EDS).[14] Thus, from a modeling perspective international treaties act as constraints in the government's multi-criteria optimization problem. However, it can also be argued that since countries are sovereign, they can terminate international contracts at any time, a fear that with respect to the United States arose after the election of Donald Trump (Elkerbout, 2016).

[14] www.bmub.bund.de/P3634/ retrieved January 4th 2017

3.5 Researchers

Researchers accompany the development of green technologies from the beginning, i.e. from basic research, over phases of initial technology application until the improving and re-thinking of current standard technologies. For example, Becquerel (1839) discovered the underlying physical effects of photovoltaic cells. In the 1950s scientists from the field of space travel developed the first application of photovoltaic cells in context of the American space program. Until today research is done to further improve the efficiency of photovoltaic cells. Since 1975 the maximum efficiency thus has been increased from 22% to 46%.[15]

Of course, research is depending on funding. By funding of certain researchers actors can thus have a great influence on the speed of technological progress in a certain area and hence on the speed of its diffusion. Typically, the largest part of funding for the development of green technologies comes from governments and state-owned organizations. In this regard, Azadi et al. (2016) could show that in case of bio-fuels research expenditures of governments and scientific output have been highly correlated. Substantial funding for the research in green technologies is also provided by manufacturers, infrastructure and lobbyism organizations.

However, for researchers the acceptance of external funding - which often is required or at least honored by their research institutions - can result in a dilemma. Research, which is considered more useful to society or science, may have to be given lower priority just to serve the particular interests of individual donors. Even worse, the dependence of external funding may in certain cases lead to biased studies or even faked results (Nürnberger, 2005).

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[15] National Renewable Energy Laboratory

4. Green Finance: A short literature review

Obviously, the interaction of various uncertainties and game-theoretic dependencies in the research field can hardly be comprehensively modeled or analyzed. Thus, research in the field of Green Finance research usually focus on a certain aspects or otherwise has to use drastic simplifications.

At first, a research strand discusses the advantages and disadvantages of certain green technologies - mostly in the field of renewable energy (see e.g. Klessmann et al., 2008; Akella et al., 2009; Burgos-Payán et al., 2013). Some researchers also just discuss certain disadvantages, for example landscape externalities caused by wind power projects (Meyerhoff et al., 2010), or in case of bio-diesel production environmental damages at palm oil plantations (Fitzherbert et al., 2008), and the competition to food production (Ford Runge and Senauer, 2007).

Another research strand discusses if certain green technologies are efficient from an investor's perspective. In particular, it is analyzed if the technologies break even. For example, Kopp et al. (2012) analyze the situation for diverse renewable electricity technologies, Harder and Gibson (2011) and Hagerman et al. (2016) consider the profitability solar electricity and Benitez et al. (2008) investigate the economics of the combination of wind power production with energy storage. In case of energy-efficiency technologies Berry and Davidson (2015) test the profitability of zero-energy homes and Miller et al. (2008) study empirically if energy-efficiency investments in commercial real estate pays off. Finally, İşlegen and Reichelstein (2011) examine the break-even value of carbon capture and storage technologies for newly built conventional power plants.

Related research deals with the selection of the most suitable technology, for example, between alternative energy technologies (Siddiqui and Fleten, 2010), between renewable energy production and carbon capture and storage (Rohlfs and Madlener, 2013), between hybrid or electric vehicles (Nishihara, 2010), within the field of photovoltaic cells (García-Cascales et al., 2012) or within the field of bio-fuels (Tao and Aden, 2009).

However, to determine from an investor's perspective whether an investment in a green technology pays off and which technology is the most promising, it is necessary to estimate the respective cost and earnings. In case of renewable electricity investments, in case of investments in carbon capture and storage as well as in case of investments in the production of bio-fuels, the earnings depend on commodity prices that are traded on an exchange and that evolve stochastically over time. Consequently, a research strand exists that deals with the stochastic modulation of carbon emission allowance prices and its derivatives (see e.g. Abadie and Chamorro, 2008; Cetin and Verschuere, 2009; Daskalakis et al., 2009; Jaehn and Letmathe, 2010; Dannenberg and Ehrenfeld, 2011; Chevallier and Sévi, 2013). Likewise, research is done on the stochastic behavior of electricity prices (see e.g. Fleten and Kristoffersen, 2007; Gil Zapata and Maya Ochoa, 2008; Kovacevic and Paraschiv, 2014) and of the price of alternative fuels (Bastian-Pinto et al., 2009).

On the meta-level, another research strand examines the process of the diffusion of green technologies, especially renewable energy technologies (see e.g. Jacobsson and Bergek, 2004; Madlener et al., 2005; Jacobsson and Lauber, 2006; Kumbaroğlu et al., 2008). Of great importance for the diffusion of technologies is the speed of progress on the learning curve, i.e. how fast do the technologies cost decline over time. Several studies deal with the forecast of future cost of future technology and determine the causes for the progress on the learning curve. Examples are Pillai (2015) in case of photovoltaic and Lantz et al. (2012) in case of wind power technology. It is also of particular interest how progress on the learning curve can be specifically promoted (see e.g. Foxon et al., 2005; Kosugi, 2013; Azadi et al., 2016). However, it is also seen that the speed and the result of technological progress are uncertain. For example, Koelbl et al. (2014) analyze the technological uncertainties regarding the development and diffusion of carbon capture and storage technologies. As a consequence of technological uncertainty Fuss and Szolgayová (2010) argue that investors should not just use a break-even analysis to evaluate investment decisions but to use a decision rule that takes technological uncertainty into account. As a result any uncertainty associated with the technological progress of renewable energy technologies should lead to a postponement of investment. In this regard Meijer et al. (2007) could empirically show that technological uncertainty actually delays investments in renewable energies. Only recently, Torani et al. (2016) argue that it is not just technological uncertainty but also an expected fast progress on the learning curve in the near future that should let potential investors wait with their investments.

Not only with respect to green investments but in most cases of investments under uncertainty real options have been proven to be a valuable tool to analyze investment decisions under uncertainty and to especially account for the flexibility of the investor to wait with an investment - either until uncertainty has at least partially resolved or until expected cost reductions have been achieved. A good introduction to the concept of real options and their implementation is given by Dixit and Pindyck (1994) and Trigeorgis (1999).

With respect to Green Finance already a pronounced research strand exists that analyzes the investors' decision regarding green investments from a real option perspective. However, so far, usually not technological uncertainties but market price uncertainties are considered. In particular, Cortazar et al. (1998) use the real option approach to deal with green investment decisions in general. Likewise, Sarkis and Tamarkin (2008) use real options to analyze all kind of investments in renewable energy projects. More specialized, the real option approach is used in case of bio-fuels (Pederson and Zou, 2009), wind power (Fleten et al., 2007; Muñoz et al., 2011), hydro power (Chaton and Doucet, 2003; Bøckman et al., 2008; Martínez-Ceseña and Mutale, 2011), geothermal energy (Moreira et al., 2004), biomass (Di Corato and Moretto, 2011), solar power (Zhang et al., 2016; Welling, 2016a), energy efficiency (Abadie et al., 2010) as well as the reduction of carbon and other emissions (Kort, 1995; Insley, 2003; Abadie and Chamorro, 2008).

However, research on Green Finance does not only consider the investment decision but also considers the financing aspects of green investments, i.e. the source of financial resources. For example, Criscuolo and Menon (2015) analyze the determinants of venture capital with respect to green investments, Tang et al. (2012) show how carbon revenue bonds can help to finance green investments and Bohl et al. (2013) investigate the performance of renewable energy stocks. Interestingly, Chava (2014), could show that green investments have an influence on the capital structure of companies, particularly increasing the equity share.

Furthermore, Green Finance does not only consider the perspective of single investors but also of manufacturers - for example manufacturers of photovoltaic cells (Goodrich et al., 2013) and whole supply chains. In particular, the question how to increase the sustainability of supply chains is receiving strong attention, especially from the field of operations research (see e.g. Linton et al., 2007; Zhang and Liu, 2013). Good reviews on these research field are provided by Seuring and Müller (2008) and Brandenburg and Rebs (2015). The review of Dekker et al. (2012) specializes on the sub-problem of green logistics. A substantial part on the research on sustainable supply chains deals with the reduction of the supply-chain's carbon footprint (see e.g. Du et al., 2011; Abdallah et al., 2012; Chaabane et al., 2012; Elhedhli and Merrick, 2012; Benjaafar et al., 2013; Dong et al., 2014; Lukas and Welling, 2014).

A total different research strand in the field of Green Finance that is closely linked to environmental economics focusses on the analysis of policies regarding the support of green technologies. For example, Kumbaroglu and Madlener (2003) develop a method for the macroscopic analysis of a country's energy and climate policy, Detert and Kotani (2013) set up a model that allows to determine when a country should change its policy from supporting conventional power to the support of renewable electricity and Helm (2014) discusses the whole European framework of energy and climate policies. More specifically, Galvin (2010) discusses the German policy regarding the thermal insulation of residential real estate and Sorda et al. (2010) give an overview on the possibilities to support bio-fuels.

Likewise, the governmental support of carbon emissions reduction is subject to much research. Here, with carbon taxation and cap-and-trade two different support systems are used by governments throughout the world. With respect to cap-and-trade a good review on the history, function and success of the European Union Emissions Trading System is given by Ellerman and Buchner (2007). For a brief discussion on carbon taxation see e.g. Proost and Regemorter (1992), Zhang, Zhong Xiang and Baranzini (2004), and Avi-Yonah and Uhlmann (2009):

Further, many researchers analyze the governmental support of renewable electricity. An overview of the various systems and their advantages and disadvantages is given by Ackermann et al. (2001) and Haas et al. (2004). Focusing on only one support system Kahn (1996) disapproves the concept of tax credits, Helm (2002) criticizes the system of renewable quotas and obligations trading, Duke et al. (2005) discuss the effect of net-metering (a producer of renewable electricity can feed excess electricity in the grid and later use the same amount for free) for private photovoltaic investments, Zipp (2015) analyzes the effect of fixed feed-in tariffs on the orientation of photovoltaic cells, and Mudasser et al. (2015) demonstrate the effect of location-dependent fixed feed-in tariffs. Gan et al. (2007) compares the policies of different countries. Likewise, Mitchell et al. (2006) compare fixed feed-in tariffs with renewable quotas, and Garcia-Bernabeu et al. (2015) compare fixed feed-in tariffs with a support system based on market prices.

A related research strand analyzes the effects of a sudden change in a governmental support scheme as well as the process of a careful adjustment of governmental support schemes. For example, Büsgen and Dürrschmidt (2009) describe the evolution of the German feed-in tariff support scheme and Munksgaard and Morthorst (2008) show the effects of a sudden switch in the Danish support system of wind power. In this regard several authors discuss the reasons for political action and the manner of political decision-making (see e.g. van der Horst, 2007; Wüstenhagen et al., 2007; Hoppmann et al., 2014; Sühlsen and Hisschemöller, 2014). However, it may well be noted that political decision-making is far away from being deterministic. Lüthi and Wüstenhagen (2012) argue that although under fixed feed-in tariff support schemes renewable electricity investments seem to be almost riskless investors should better take into account the political uncertainty regarding a possible regime switch. Indeed, Meijer et al. (2007) could empirically show that political uncertainties weaken the investment activity regarding renewables. Yang et al. (2008) and Boomsma et al. (2012) both set up a real option model to analyze optimal investment decisions in the context of renewable electricity investments under the presence of economic and political uncertainty.

Likewise, in Welling et al. (2015) the potential investor of a green project faces economic as well as political uncertainty. The investment decision is modeled and analyzed by means of real options with the special feature that the political uncertainty totally resolves at the next election day. The article also sets lights on the different effect of political risk and political ambiguity (or Knightian uncertainty) on the investment decision.

Finally, an important research strand in the field of Green Finance tries to determine the optimal policy of governments to support green investments. Therefore, at a first step, the reaction function of the investors has to be determined. In particular, to be able to optimize the policy it has to be known, how exactly the investment activity depends on the governmental support. Dinica (2006) argues that the risk/profitability characteristics induced by a support scheme determine the investment activity. Some researchers empirically analyze the reaction function of investors. For example, Barradale (2014) investigates the industries feelings regarding political uncertainty and their expectations for future regulations and Linnerud et al. (2014) determine the reaction function of hydro power investors. Interestingly, they could show that different classes of investors react differently. In particular, institutional investors act in accordance to real option theory, i.e. they wait with the investment if political uncertainty is high, while the reaction of private investors does not depend on uncertainty regarding a political regime shift. Zhang et al. (2013) have developed an equilibrium model that allows to determine the reaction of whole bio-fuel producing supply chains on certain governmental policies and Wickart and Madlener (2007) discuss the effects of carbon taxation on the investment activity. Boomsma et al. (2012) have set up a real option model that determines the reaction of investors, i.e. investment timing and investment capacity, in dependence of the different governmental support schemes.

Building on the model of Boomsma et al. (2012) Welling (2016b) analyzes the effect of an increase or decrease of a certain type of governmental support on the investment activity. Paradoxically, it can be shown that an increase of governmental support over time may weaken the investment activity.

Furthermore, to be able to optimize the governmental policy, as a second step, the objective has to be determined with regard to which the policy shall be optimal. For example, Schmidheiny (1992) developed the objective of eco-efficiency as "the ratio between the (added) value of what has been produced (e.g. GDP) and the (added) environment impacts of the product or service". Additionally, a way has to be defined how the achievement of the objectives shall be measured. In this regard, Chen (2014) explains and compares two methods to measure eco-efficiency, while Lee (2012) and Schaltegger and Csutora (2012) focus on carbon accounting, i.e. a way to measure carbon emissions of plants or supply chains.

On one hand optimizing governmental support can mean to slightly adjust existing support schemes. For example, Langniß et al. (2009) propose three different ways to optimally develop the German support of renewable electricity and Kosugi (2013) analyzes how to optimally adjust fixed feed-in tariffs if investment cost decrease due to progress on the learning curve. On the other hand optimizing governmental support can mean to develop a new optimal system. Here, Pindyck (2002), and building on this paper Lin et al. (2007), develop a real option model to determine the optimal timing of governmental action, Stadler et al. (2007) develop a simulation tool that allows to determine how public money can be spent most efficiently to promote sustainable energy systems, Du et al. (2012) analyze the optimal cap in a cap-and-trade system for carbon, and Eckhause and Herold (2014) use stochastic dynamic programming to obtain optimal funding solutions under uncertainty. Other researchers are working on methods that are adapted to problems in the field of green finance and allow to model and solve optimization problems with multiple objectives (see e.g. Konidari and Mavrakis, 2007 ; Oliveira et al., 2014). For example, Blechinger and Shah (2011), use the multi-criteria of Konidari and Mavrakis (2007) to evaluate policy measures for climate change mitigation Trinidad and Tobago.

5. Conclusion

Green Finance is a very diverse research field that strongly application-orientated deals with many different - and often highly complex - problems. Although there already exists a rich literature on certain aspects, political and technological developments guarantee, that new problems arise unremittingly, that can be analyzed, modeled, evaluated, and optimized. In the following, some of these emerging problem areas are presented. In particular, those, of which the author assumes, that they will be increasingly focused on by researchers in the future.

Firstly, after the successful diffusion of renewable electricity technologies governments around the world are faced with the task of adjusting their support systems. A prime objective is to slowly adjust the remuneration for the production of renewable electricity to the actual economic value produced. In the first instance, the aim should not be an abrupt or a strong reduction in overall funding, which could seriously damage whole industrial branches. Instead, the task will be to carefully link the enumeration of renewable electricity to market prices to take into account the place and the time of the production of renewable electricity. Especially, under strict fixed feed-in tariff support schemes the time and place of production, so far, had no influence.

In this regard two other problem fields arise. On one hand, there is the task to find a way to reward the provision of reserve capacity in the form of fast-rising but expensive power plants; on the other hand storage technologies become more and more important. Open research questions are the choice of the best technology, the technical and economic interplay with renewable energies, the impact on the electricity market and on electricity prices, as well as the appropriate governmental support of storage technologies and their further technological development. Finally, smart grid technologies can be an alternative to support grid stability. Here, with the help of new data transmission technologies of machine-to-machine communication the electricity consumption is intelligently controlled using market data, i.e. the demand takes the stochastic production quantity into account.

Another major challenge in the research field of Green Finance lies in the current trend of increasing political uncertainties. International terrorism, financial crises, the regression of democracies into autocracy, the increased presence of populist parties and persons, and the increasing skepticism towards international institutions and towards free trade, they all have the consequence that political decision-making is becoming more and more ambiguous; especially in case of green technologies, where decisions are often made internationally. Hence, research should give special attention to negotiations on climate summits, to the prediction of election outcomes and their consequences for green investments, and to the analysis of international negotiations, such as the Brexit.

Finally, big tasks arise with the transition of fossil-fuel based mobility towards sustainable and alternative mobility. In particular, an increased use of electric cars will have major impacts on electricity grids, grid stability, and market prices for electricity. Consequently, this will also have an impact on investments in renewable energies, on investments in electricity storage and on investments in energy efficiency

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Otto von Guericke University Magdeburg
Faculty of Economics and Management
P.O. Box 4120 | 39016 Magdeburg | Germany

Tel.: +49 (0) 3 91 / 67-1 85 84
Fax: +49 (0) 3 91 / 67-1 21 20

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ISSN 1615-4274