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Policy mix and the impact on PV technologies and industry: The challenge - How to make policies quantifiable?

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Abstract

In the framework of the research project (Gretchen) financed by the German Federal Ministry of Education and Research, the impact of German policies on industry structure and technological change is investigated. As the quantitative impact analysis of German policies on technologies and structures is complex and requires a comprehensive approach, this paper focuses on a selected part of the analysis: It explores and discusses the possibilities of how to quantify and operationalize German policies addressing photovoltaic electricity generation. This is done for the case of PV. The impact analysis of the policies will be discussed in a separate paper.

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Table of Contents

Page

1 Introduction

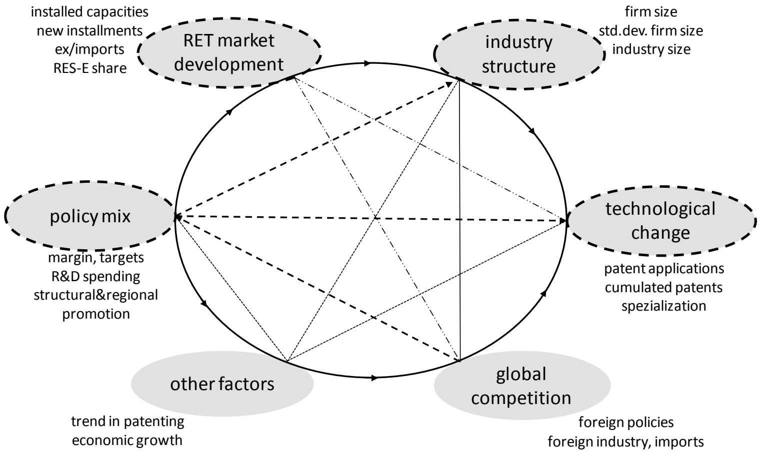
Since 1990 the share of renewable energy (RE) in the German power generation mix has grown enormously. The feed-in tariff scheme (FIT) in Germany has been very successful in increasing renewable energy technology deployment. This growth has been accompanied or pushed by diverse policies, which entails costs as well as benefits at the system-, the macro- and micro-economic level (ISI et al. 2014). Technological change is regarded as one major positive effect of RE promotion policies. Based on approaches from industrial organizations and functions of a technological innovation system (TIS) described in Hekkert and Negro (2009), del Rio and Bleda (2012), the research approach of the Gretchen Project looks at the different functions of an innovation system. It investigates how demand-pull, technology-push and industry support policies affect innovation functions such as knowledge development, entrepreneurial experimentation and market formation. However, the impact of policies is not unilateral but mutual, meaning that entrepreneurial activities or market formation also affect policies. Further, the impact of German RE policies on industries abroad will be looked at as demand support policies have cross-border effects (Peters et al. 2012).

This complex relationship between policies, markets, industries and technologies is depicted as the research framework in Figure 1. It illustrates the interdependency not only among the German policies and technologies but also includes foreign policies and industry structures because foreign as well as domestic supportive public policies can influence domestic industries (Lund 2009).

As the research scope is rather complex, the approach will be divided into two studies. This paper centers on the operationalization of policies and their use for quantitative analysis: it explicitly discusses how to quantify and operationalize policies, a mix of instruments or policies to analyze their impact. The focus is limited on PV related policies and impacts. Based on these results, further analyses on the impact of policies will follow in a separate paper.

Summed up, the objective of this paper is to derive quantifiable policy indicators allowing a quantitative policy impacts assessment in the case of PV in Germany. The latter will be described in a separate paper (Breitschopf 2015).

Figure 1: Research framework: policies, market, industry and technology for PV



In a first step, a literature review on how policies are operationalized and used for quantitative analysis is given. This is followed by the selection of appropriate policies addressing knowledge generation and market formation in PV, derivation of appropriate policy variables or indicators and their quantitative values. The paper concludes with a critical discussion of the findings and a brief outlook.

2 Literature review

In a first step we review papers which analyze energy policy impacts on technologies, industries or markets. Thereby the main focus is put on what types of policies are used for the analysis and how are they quantified. Based on Lehr et al. (2014), the energy policies are grouped into four policy categories:

1. instruments that foster demand for RE technologies (called demand focused policies or demand-pull policies) by explicitly addressing demand for PV modules, e.g. FIT guaranteed by the RE act in Germany
2. policies that support technological changes, improve knowledge and networking, e.g. public R&E support.[1]
3. policies with a special focus on manufacturers (supplier focused policies), e.g. investment grants, interest subsidies, facilitated access to land property, and finally

1 In the style of innovation economics R&D policies are also called technology push technologies.

4. a policy or instrument mix that incorporate the effect of several instruments or policies to capture interactions of these policies on technological changes.

1. Demand focused policies

Papers investigating the relevance of energy policies in shaping renewable energy markets or RE deployment stress the significance of demand pull instruments such as the feed-in scheme (FIT) for innovation functions. To measure or evaluate the impact of RE market support policies a variety of proxies such as growth rates of installed capacities or RE-based generation, market shares of RE generation or capacities, cumulated or new capacity installments in MW per annum, targets, capacity relative to targets, price of power generated from RE (Wüstenhagen and Bilharz, 2004; Jacobsson and Lauber, 2006; Jenner et al. 2013, Butler and Neuhoff, 2008, Brand and Zingerle 2010) but also equity aspects and fiscal responsibility (Sovacool, 2010) are used. Beyond these measures, some of these authors approach the “policy quantification” challenge by applying rankings, implementing preference analysis, discussing interactions or efficiency of policies.

For example, Bürer’s and Wüstenhagen’s (2009) operationalization of policies is based on a survey resulting in a ranking of policies according to their perceived effectiveness. Similarly, Masini and Menichetti (2012) employ a conjoint analysis to capture preferences for selected policy features of investors. For this purpose they used attributes for policies: type of policy, level of incentive and duration of support and administrative process. The results suggest that the RE share in the investors’ portfolio is positively related to FIT and duration of support.

Regarding ”new policy variables”, Yin and Powers (2009) have created an incremental percentage requirement variable reflecting the mandated increase in RE generation to meet the renewable power standards. Moreover, they use binary variables to take into account the existence of renewable portfolio standards at federal and national levels of the US as well to integrate further policy instruments. They address different policies and policy design features as well as further social and economic factors. Their findings show that ignoring differences in policy design might blur the impacts of these policies.

Following Yin and Powers (2009), Jenner et al. 2013 developed a kind of new indicator for policy strength: the return on investment (ROI). It encompasses different tariff sizes, contract duration, digression rate of support, electricity price, electricity generation costs capturing also investment and O&M expenditures. Based on this indicator the authors strive to explain cumulated and annual added RE capacity (variable to measure impact) and assess the effectiveness of FIT policies. To account for technical, political and country specific characteristics further variables are included, such as mandated increase in RE generation relative to total power generation representing the stringency of RE policies, and other RE support policies (tax, grant, tender) or design elements (caps). Their findings suggest that the interaction between power price, generation costs and policy design plays a more important role for RE use than putting just a policy in force.

When looking at the wind market and wind industry Lewis and Wiser (2007) slightly extend the scope of analysis and include policies focused on energy suppliers but still employ demand related data such as installed wind capacities and market shares. At the policy level they remain at the qualitative level but discuss in addition to the role of financial incentives and export support also the significance of local content requirements. Like Lewis and Wiser (2007), Grau et al. (2012) include more policy instruments in their analysis. But they are not restricted to demand support policies, which they capture in terms of FIT per kwh and monetary support volume per year, but also take into account research and firm specific supports. However, they refrain from analyzing the potential interaction of these policies.

2. Technology-push policies

In contrast to RE market support policies, the public R&D spending for RE technology is a very commonly used policy variable. The R&D spending is measured by just a few indicators such as public R&D spending for technological developments or exploration, the number or frequency of networking and cooperation, and if available, private R&D spending. To capture the impact of R&D spending, technology cost development, patent applications, and network size or cooperation are applied as measures by e.g. Peters et al., 2012; Wüstenhagen and Bilharz 2004, Grau et al. 2012, del Rio and Bleda 2012, Johnstone et al. 2008. Also further complementary policies such as education or infrastructure policies are recognized as being important for economic development (e.g. Benhassine and Raballand (2009), Barbieri et al (2012), Breznitz (2007)) and for RE value creation (e.g. Lehr et al. 2014), studies explicitly investigating the impact of policies addressing education or training in RE technologies, project development or management or infrastructure development, on RE deployment could not be found.

3. Supplier focused policies

Supplier focused policies such as investment grants or tax incentives address directly the industry structure. Grau et al. (2012) explore the development of the PV industry and policies in Germany and China. They divide PV related policies into PV deployment instruments, R&D and investment support policies of manufacturers. They list investment grants, reduced interest loans, public guarantees for manufacturer as measures for supplier focused policies, and qualitatively discuss the potential effects of these policies on technological development. Many other authors such as Dewald (2011), Khammas (2013), have intensively collected data on respective support policies affecting this industry but their analysis remains at a descriptive level.

4. Policy mix

When investigating the impact of policies, one and a half decades ago Rennings (2000) and other authors were aware of the fact that not a single instrument, but a mix of instruments as well as other aspects such as a policy strategy, consideration of innovation phases, implementation and policy making and factors that are beyond policies exert a strong influence on technology advances and use.

In recent years, Lewis and Wiser (2007) conclude from their analysis on wind industry policy support mechanisms that RE demand policies in combination with policies supporting local wind power technology manufacturing are most likely to promote the development of an internationally competitive industry. Thus, according to them, the mix of policy instruments as well as a stable and sizable home market fosters the growth of the industry. With respect to the instrument mix, Grau et al. (2012) discuss the significance of demand support instruments (FIT and financial support volume) as well as the impact of investment grants for manufacturers (supplier focused policies). However, they did not econometrically explore the effects of these policies on market and technological development. A different approach is pursued by Kranzl et al. (2013). They integrated two types of policy instruments - one instrument providing an economic incentive such as investment subsidies, and the other one, obligations, requiring a certain share or quota of RE use – into their model. Their results show that both instruments contribute to an increased use of RE but that this use corresponds not always to the generation targets given in the NREAPs (National Renewable Energy Action Plans), which is pointing to inconsistencies between targets and instruments. Since they are working with a simulation model the operationalization of policies is done via technology or generation costs and a constraint condition. Compared to many other authors, the research question pursued by Peters et al. (2012) is more specific and centers around the loci of policies. For their analysis they apply domestic and foreign PV capacity additions as a proxy for demand pull policies and R&D funding for technology push policies. The main findings of this study are that technology push studies hardly have any impact outside the national borders while demand pull policies trigger also innovative activities in firms abroad, or vice versa, foreign demand pull policies induce also innovation in the domestic industry. Consequently, RE market demand policies could create cross country spill-over effects and, thus should be designed at a supranational level, i.e. domestic and foreign policy instruments should be consistent.

The importance of policy consistency is investigated in White et al. (2013). The authors emphasize the significance of certainty in policies and economy for future investments. They argue that abrupt or unforeseen policy changes increase uncertainty about future policies and hence make investments in RE more expensive. Their measure of consistency is, however, not the policy change itself, but the “manner in which policies are changed” i.e. the “sudden and unexpected policy changes”, but they have not developed a measure for “sudden changes”. Similarly, Stokes (2013) analyses how political processes influence RE policy design and its implementation. He identifies several challenges for politicians: first, to have a common line (societal and political) for RE support, second, to set the right prices and incentives because of information asymmetries, and third, to balance between adjusting policy design and assure policy stability and, finally, to handle simultaneously pursued RE industry growth objectives that could result in conflicts over jobs and innovations. Overall, he emphasizes the importance of policy making, implementation or adjustments and stability.

Jacobsson and Lauber (2006) point out that the diffusion of PV and wind technologies was embedded in a political process as well as in a regulatory and research framework that have been shaped by external factors, namely the energy crisis and Chernobyl. In addition, the nature of the employed policy instruments, i.e. the right and timely mix of instruments contributed to strongly increasing RE deployment. Thus, processes, procedures, visions and the bundle of instruments as well as external factors are considered as essential for a successful RE technology diffusion. However, the quantification of policies remains a challenge. Lipp (2007) derived similar results in her analysis. She qualitatively investigates the effectiveness of different policies by looking into policy objectives and using RE penetration, avoided emissions, innovation and employment in RE as a “success” indicator of a policy. Her findings suggest that a clear policy commitment, respective design details and implementation is crucial for an effective and efficient policy. While she used goals or targets as a measure for clarity and commitment, the long-term planning horizon as well as fixed price mechanism and the technology specific support for RE are considered as central design features.

Summary

As shown above, the impact of policies has been evaluated and assessed in a variety of papers with different research backgrounds. Many of these papers describe and analyze policies in a qualitative manner. Some authors work with simple quantitative policy variables or create a “composite” policy variable. Moreover, capacity or generation data are very often used to depict policies although they reflect RE technology deployment. Rather, they are indicators for the innovation function “market development”. Even though the interaction of policy instruments, strategies and policy processes is considered as important, most of the authors struggle with the implementation of “interaction” in their analysis. Apart from a few regression analyses where the effect of different instruments is quantified, interactions have not been explored in more detail.

Finally, many authors recognize the importance of a broader use of the term “policy”, but they remain rather vague in exactly defining policy and refrained from using an “indicator” or an analytical tool that somehow reflects or allows conclusions regarding policy mix. The results of the literature review with respect to the approaches quantifying or operationalizing policy variables are depicted in Table 1.

Table 1: Literature review: Diverse measures of policies and approaches to analyze impacts of policies

Indicators used to discuss…	

Renewable deployment policy:
 	
Capacity based:
• Volume in MW
• Growth in % or MW
• Share in %
• Incremental percentage requirement
 	
Generation based: ditto capacity
 	
Price or cost based:
• FIT in Euro/kwh
• Price of power
• System costs, LCOE
• ROI
	Policy mix:
	• Targets to depict commitment:
	  ○ in % generation or capacity
	  ○ MW
	• Relation of FIT and R&D
	• Policy efficiency or effectiveness:
	  ○ indicator (nominal: e.g. RE penetration)
	  ○ ranking (ordinal)
	  ○ design features (size of support, technology specification, digression of FIT, long term planning)
	• Consistency: Unexpected changes in policies
	• Political process (discussions), visions, implementation, policy design

Technology-push policy: Public R&D Spending in Euro • Technological development • Cooperation and networking Private R&D spending in Euro	**Supplier focused policies:** Grants: volume of investment support Taxes: volume or share of credits Local share requirement

Source: own compilation

3 Methodological approach

Hitherto, the quantification of demand policies is limited to policy instruments and neglects policy strategies or targets. Moreover, in many cases studies fail depicting adequately the pull effect of demand instruments. For example, installed generation capacities are used as a proxy for a demand-pull policy but they installed capacity are already the result of demand-pull instruments. Furthermore, using FIT as a policy proxy ignores the relation between FIT and costs (LCOE) to appropriately reflect the pull-effect. Finally, the mix of diverse instruments or policies or the interactions are not well captured. Many papers refer to commitment of policy makers, consistency or reliability of policies without providing a clear measure or definition. For this reasons, the selection of policies for operationalization is based on a broad bundle of policies addressing different levels and actors along the PV technology value chain. Second, this paper strives to better capture the pull-effect of demand instruments i.e. shows how attractive investments in PV plants are from an investor's perspective, and integrates all existing demand-pull effects into one single variable. But it goes beyond instruments and takes into account the policy strategy as well. Given these criteria, the following policies are selected:

- **Public R&D support** focusing on PV technology developers,
- **Public investment support** focusing on PV technology producers/manufactures,
- **Demand-pull instruments**: including the FIT, grants, subsidized interest rates for investments in PV power generation plants: margin, return or incentive,
- **Deployment target** to include policy strategy as part of demand pull policies,
- **Combination of policies** to show political commitment and their joint impact.

3.1 R&D policy variable – technology-push

R&D policy support is considered as an overarching policy promoting knowledge generation, exchange as well as cooperation and networking, which all are assumed to have a high potential impact on technological development. In Germany public R&D spending aims at supporting technological advances and knowledge generation through research, demonstration, networking and cooperation. As this policy instrument is assumed to push further technological developments, it is commonly called a technology-push instrument.

Data on public R&D support for PV technology development and networking (Bundesförderdatenbank) in universities, research institutes and industry are used to explain the impact of technology promoting policy support on technological changes. Public R&D spending for PV has been selected by keywords such as PV module, cell, wafer, silicon. Because research institutions closely collaborate with industries there has not been made a distinction between R&D spending for industry or institutions. As public spending data are published by approval time and not by actual payments, a moving average of three years is applied.

3.2 Public investment support – supplier focused policy

Besides energy demand policies that refer mainly to PV deployment other policies exist that do not focus on PV deployment but on manufacturing firms or industries directly – selective policies. They push industries by providing public support for investments. Consequently, they have a potential effect on technologies and industry structures. To capture this push effect, data on the German joint task program (GRW) initiated to improve regional structures, as well as the EU Fond (EFRE) for regional development, are used. Both programs provide subsidies for industry investments in selected regions and industries. They are considered as a significant supplier focused policy impacting structures as well as technologies. Similar data have been used by Grau et al. (2013) as well.

Support rates vary between regions, i.e. regions with low economic development receive a higher support share. The data for investment grants (GRW) are available per German NACE industry classification from 1990 onwards. To figure out how strongly the PV technology manufacturing industries have been supported in their investment activities, the financial supports for the selected German NACE industries (WZ(2008) 2611, (2003) 3210) are used. This industry includes wafer, PV cell and module manufacturing industries. The data are applied as a moving average of three years as the approval period is not equivalent to the output period (production and development). Besides this national and EU support programs regional (non-financial) supports might has been granted but no data are available on this.

3.3 Demand-pull instruments – pull and consistency

Since 1990 or even before demand-pull instruments to foster demand for PV plants have been in force. At the beginning regional programs, support from utilities and initial public programs (e.g. 1000 roof top program) have supported demand. They were complemented or followed by loan and FIT programs. Some of them were simultaneously in force. To show the combined effect, a composite variable will be created that integrates all pull-effects of the deployment instruments. A comparison between the variable with and without the diverse pull instruments shows how strong this pull effect has been and hence how consistent these instruments were. In this context, consistency of instruments is understood as a mix of instruments not conflicting in objectives, pursuing similar goals and increasing profitability of an investment in PV, but not excessively supporting them.

To derive this composite variable, the risk and profitability characteristics of investments in PV power generation are taken into account. Especially expected profits influence the rate of diffusion of RE technologies (compare among others Dinica 2006). Hence, it is assumed that technologies with low profitability display a low deployment level and vice versa. Policies affecting profitability of an investment also affect deployment and market development of these technologies. In the case of PV policy variable is elaborated. This variable captures and integrates the different effects of all demand instruments on the cash flow of an investment and hence on profitability. Thus, it comprises the financial aspects of grants, subsidized interest rates or feed-in supports. We assume that the expected profit – net value of expenditures and revenues – is suited to show the attractiveness of an investment from an investor's point of view, and, hence, brings to light its pull effect for market development and diffusion.

The composite policy variable "**margin** $_{\text{with support}}$" – profit per generation unit – depicts the difference between the revenues (feed-in tariffs (FIT)) and the levelized cost of electricity generation (LCOE) adjusted by support policies (e.g. investment supports, interest subsidies, grants). The margin is calculated as:

$$Margin_t = revenues - (LCOE - discounted\ specific\ support) \quad (1)$$

revenues: per unit of electricity, e.g. feed-in tariff or power price or annual compensation payment;

supports: interest subsidies, production tax reliefs, etc. …. per unit of electricity

To account for investment support, grant or subsidized interest rate below the market deposit rate, a cost credit (discounted support per unit of electricity) that reduces the levelized cost of electricity (LCOE) is applied. To assess the LCOE, investment costs, operation and maintenance costs as well as module efficiency and performance rates for each year (1980 to 2012) are included in the calculations. The "margin $_{\text{without support}}$" presents the difference between the electricity price of households (avoided costs) and the LCOE without any discounts. The figures are based on a small PV generation plant of up to 10 kW (for further details, see Annex A-Table 2). Further, the share of self-produced power consumption is also taken into account.

The difference between the FIT and LCOE adjusted by different PV support instruments provides a margin that serves as a proxy to measure the pull effect of PV instruments on PV deployment and hence on the PV industry. But it is also seen as a variable reflecting consistency of the PV instrument mix as it displays the joint final effect of several demand focused instruments on investors' profit expectations. For example, a consistent instrument mix does not allow for extreme windfall profits or negative returns. Data on costs and support programs are based on Fraunhofer ISE (2013), Dewald (2011), BSW (2011ff), Khammas (2013), DIW et al. (1997) and own sources.

In addition, two further variables – **return and incentive** – based on the margin are created. The return relates the margin to the LCOE, the incentive takes the differences between the margin with support and without support. The first allows depicting the pull effect in relation to the costs and avoids the negative aspects of absolute values. The second eliminates the effect of technology costs which are also determined by the market development (competition).

The effect of demand-pull instruments is that the higher the profit per investment, the larger is the demand for investments in PV, and, the more the PV cell or module production or imports increase. And, as increasing demand boosts supply the market grows and develops, the number of actors and production volume increases. Firms seek to strengthen their competitiveness either by increasing their exploitation of production capacities and/or exploration of the technology potential (Hoppmann et al. (2013)). Subsequently, demand policies could either contribute to an increase of PV module production/output or to technological explorations, and this in turn, could also lead to technological changes.

3.4 Policy variable target – predictability

Very early in the 1990s technology specific deployment targets were set for PV in Germany. They were indicated in megawatts. With the Renewable Energy Act in 2000 a relative target for RE was established relating to the share of electricity generated. It is not technology specific and has been adjusted several times because actual RE deployment developed rapidly and achieved the targets before the envisaged target year (see Annex A-Figure 1). In impact analysis studies targets are recognized as an important factor. However, there is hardly any operationalized policy target variable in literature used as exogenous variable to explain for example diffusion or innovations in RET. Because targets reflect the magnitude of RE deployments and the time span for project planning and, hence, predictability, we have developed a so-called policy target variable. This variable integrates the investment potential in year t+i in relation to the target in year t+n, weighted by the difference between target year t+n and actual year t+i and the target size in year t+n.

$$Target_{t+i} = \{tar_{t+n} - deploy_{t+i}) / tar_{t+n}\} * (year_{t+n} - year_{t+i}) * size_{t+n} \qquad (2)$$

tar: target in % or MW; deploy : deployment level in % or MW in t+i; size : GWh or MW magnitude of target; t: time period; t+n : target year; t+i: observation year

The factor “year” accounts for the long-term perspective while the size should capture the extent or magnitude of the target. The relation of open capacity to target ensures that the target setting is still effective. Furthermore, to take into account the potential effects of discussions before the introduction of a target, we include signaling effects before the actual target setting comes into force by using 20%, 5% and 0.5% of the target variable’s value. The value takes zero, if no targets for PV or RE in general are published (before 1990). The assumption behind this target variable is that a large and long-term market development potential spurs innovative activities, which help to gain competitiveness and to ensure a good market position.

3.5 Combination of policies

The evolvement, combination, interaction and consistency of policies, the predictability as well as commitment of policy makers are considered as crucial characteristics for successfully achieving (deployment) goals or transforming energy provision. However, these characteristics are not clearly defined and quantifiable. This paper intends to address these issues as well.

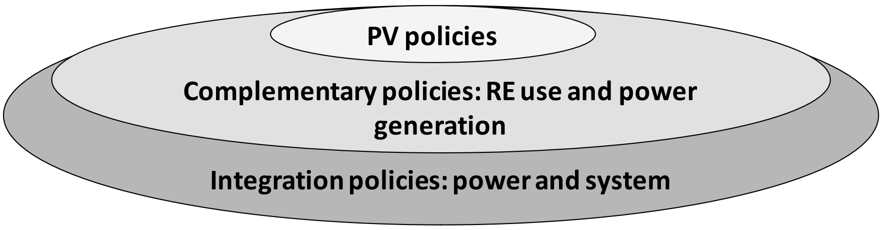
3.5.1 Policy count – a measure for commitment?

The policy count variable captures all German and EU policies positively affecting deployment and technological development in the renewable energy field. It is supposed to reflect how seriously policy makers pursue their objectives. The more policies, including implementations, discussion platforms etc. are in force, the more policy makers seek to achieve their deployment goals. Therefore, the number of policies enforcing deployment is used as a proxy for commitment. Moreover, the policies are distinguished by their level and type to show how this mix has evolved over time.

The number of policies is differentiate into different levels of policies: (1) PV-related policies, (2) complementary and (3) integration policies. The latter aim directly or indirectly at development and use of PV power generation technologies. Each level distinguishes the type of policy: policy elements including strategies and instruments, policy procedure encompassing policy making and implementation[2]:

- PV-related policies: They refer to all policies that directly and immediately but not necessarily exclusively affect PV deployment. These policies are labeled “PV-related policies”. In addition, a distinction is made within this level between PV-related policy strategy, instruments, policy making and implementation. PV related strategies are plans or long-term targets for PV – eventually also for other RE – revealed in energy concepts, roadmaps or deployment plans. PV-related instruments focus at least in one aspect of their design on PV deployment or technology development. Similarly, policy making and implementation includes formalized information, evaluation (procedure), institutions, ordinances and implementation rules that refer at least in one aspect to PV deployment as well.
- Complementary RE policies: They comprise policies aiming not explicitly at PV but at RE deployment and power generation. They are considered as complementary policies since they pursue complementary objectives and indirectly support the use of PV for power generation. They are differentiated into strategies, instruments, policy making and implementation as well.
- Integration policies: Policies that support but do not aim at the generation of electricity or RE use, and all policies that support the integration of RE or PV into the power system, for example the EnWG, ETS, SET Plan. They are called “integration policies”. Again it is distinguished between strategies, instruments, policy making and implementation.

Figure 2: Analytical concept for policy mix



Policies listed as strategies are strategy papers, roadmaps or concepts e.g. the Renewable Energy Roadmap of the EU (COM(2006) 848) or the Energiekonzept (energy concept) in Germany. They disclose targets and strategies how to reach the ultimate objectives. In contrast, instruments are either programs, directives or acts actively supporting the strategies and providing a

2 For more information on policies, instruments and strategies as policy elements and procedures see (Rogge and Reichert (2013))

framework for what and how to support e.g. the Renewable Energy directive of the EU (Directive 2009/28/EC). While policy making refers to processes and procedures involving stakeholders, getting support agreements or establishing targets e.g. stakeholder processes, implementation addresses all activities that support the implementation of instruments or clarifies how to apply instruments, or provide a regulation for doing so. Examples are statistical information structures, evaluation structures, adjustments of the regularly or legal body, information or registration platforms.

The principle idea of this approach is depicted in Figure 2. For Germany, an excerpt of the policies is listed in the Annex Table 1. The number of policies is counted in order to operationalize the mix op policy and the commitment. The count shows how the number or shares are changing over time. An increasing number of policies could be understood as increasing political commitment for RE deployment. However, one has to bear in mind that state interventions often entail further public activities, and misconceptions of policies might even increase the number of policies. In addition, this variable displays further weakness: there is no distinction between policies with negative or positive effects, and the count and delineation of policies between the policy levels is probably not comprehensive. Therefore, this policy variable represents an interesting but probably not sufficient measure to depict the strength of commitment. Despite these drawbacks it is considered as a proxy for commitment as it reflects at least the interest of policy makers for this policy field.

3.5.2 Evolvement and interactions of policies

To depict how different instruments or policies evolve over time, simple correlations can be used. A positive correlation is supposed to point out a similar development, trend or employment of variables i.e. policies or instruments over time. Negative correlations indicate an opposing trend of employed instruments or policies while zero correlations are seen as completely independent employment of instruments or policies. However, correlation measures neither reflect reinforcing effects nor opposing effects of policies. They display in which direction the magnitude or incentives of policies evolve over time.

In contrast, factor analysis allows conclusions on the closeness between variables. Normally the factor analysis is used to condense a large set of explaining variables to a few main explaining factors. With respect to the operationalization, a factor analysis could reveal how closely related the variables are. In case the factor analysis shows that all policy variables could be condensed to one single factor, the variables are considered as very close and homogenous, i.e. consistent in their magnitude and development over time. From a methodological point of view a step-wise regression analysis on deployment or development of RET could provide additional insight into the explaining power of each single policy variable, its contribution to market and technology development, and, hence, the consistency. To conduct these analyses good data are needed.

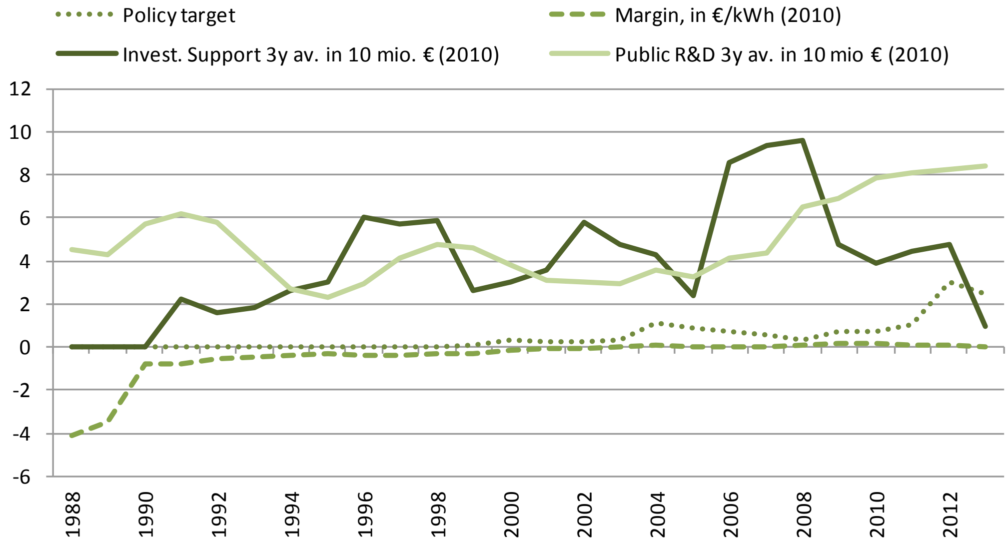
In addition, multiplicative combinations of policies are used to reflect the joint effect. For example, the combination of target with margin or public R&D support presents a policy mix – a mix between strategy and demand-pull or technology-push instruments. Finally, policy strategies and instruments as well as the implementation should be embedded in a decision process in which all parties concerned are supposed to participate. This is reflected in the social acceptance of the energy system transition, e.g. expressed in elections. From this point it follows that policy making that ensures an appropriate mix of instruments, policy making and implementation is fundamental for successful changes or transformations.

4 Quantified policy variables

4.1 Pull and push instruments

The development of the pull and push policy variables is depicted in Figure 3. It shows a fluctuating R&D and investment support policies over time for these push policies. In contrast, the target variable as a demand pull policy depicts a positive trend due to increasing deployment targets, but with decreasing phases when no new targets were set and, thus, increasing installations reduce the available deployment potential. With the launch of the demand pull instruments, the margin is steadily increasing up to a value slightly above zero.

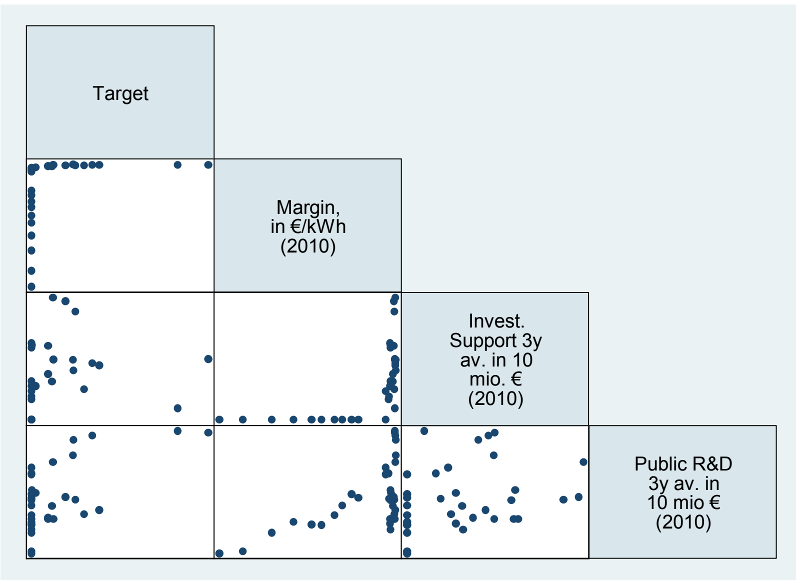
Figure 3: Development of pull and push policies over time



Source: own calculation based on data of Bundesförderdatenbank 2013, Bafa 2014 and 2014, BMWi 2014, et al. Note: price basis: 2010

Based on the assumption, that a joint development or combination of targets and demand policies is important, a strong positive correlation between margin and target and the other policies is expected. Depicting the four policy variables in a plot (Figure 4) reveals only a moderate relationship over time.

Figure 4: Correlation of policies and capacity additions



Source: own calculation

Table 2: Correlation values and significance level

	Pol_Margin	Pol_Target	Pol_R&D	Pol_Invest
Pol_Margin	1.0000			
Pol_Target	0.34 (0.41)	1.0000		
Pol_R&D	0.59* (0.003)	0.62* (0.001)	1.0000	
Pol_Invest	0.60* (0.002)	0.25 (0.81)	0.28 (0.66)	1.0000

Source: own calculation. Significance levels in ().

Likewise, the correlation results in Table 2 display a weak correlation. The unexpected low correlation between target and margin point out that policy makers first focused strongly on financial demand support instruments and neglected strategies and objectives. After 2000 targets became an issue as well. Public spending for these policies has varied independently over the years, and hence, the correlation coefficient is low. Overall, these results confirm that policy efforts have evolved over time more or less in the same direction but by varying magnitude for all four variables. This could but may not reinforce the effects of each policy. Overall, the correlation analysis shows a moderate **consistency in timing, magnitude, and continuity** of policies. Further it signals that policy makers have not employed the instruments as a mix, but separately without taking into account potential interactions.

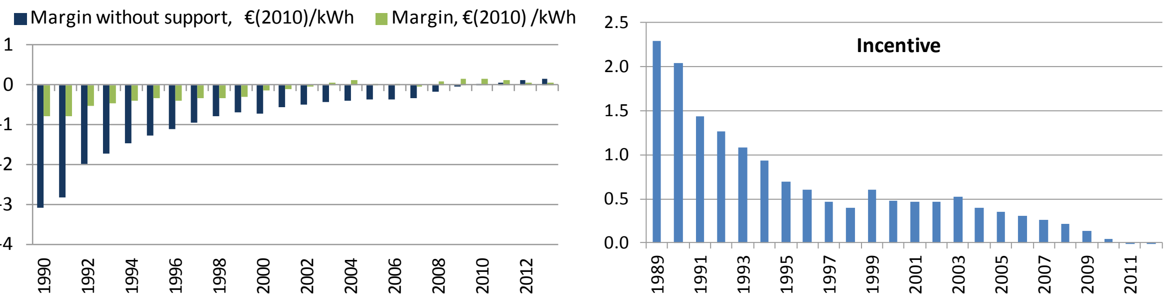
A further multivariate analysis is limited by the data. Even though the outcome of the factor analysis displays the closeness of the four policy variables, statistical tests (Kaiser-Meyer-Olkin measure = 0.51) show that the data set is not suited to pursue a factor analysis.

4.2 The instrument mix – demand pull-effect

Figure 4 shows the margins with and without support instruments. These margins are calculated on the basis of a fictive PV plant. Depending on the (spatial) location and specific cost situation of the PV plant, actual margins might differ. Initially, due to the high technology costs and low financial support, the margin (Figure 4) was highly negative but gradually reached a turning point in about 2002 due to decreasing technology costs and increasing financial support. The slight decrease in margins around 2005 and 2006 can be backtracked to an increase in module prices due to Si-scarcity while the positive margins around 2010 are the result of extremely falling PV system prices due to a large supply and a delayed adjustment of FIT by politics. Subsequently, the LCOE and, hence, the margin incorporates not only cost reducing effects of policy instruments but also the market situation or development, namely, the extension of production and increase of suppliers entering the market.

Nevertheless, Figure 5 (left) shows that financial support via investment or interest subsidies or grants considerably have reduced LCOE (of generation) and hence increased the margin even in the early 90s before the FIT (RE Act 2000) has been introduced. It also shows that the diverse policy instruments in use were quite well adjusted to their co-existence, the current financial support and cost situation: Support policies were reduced – although with a time gap – when margins became too positive. In this case, the instrument mix can be considered as rather **consistent** as there are neither too negative nor too positive margins over a longer period. It should be noted that the FIT has been the major instrument in force for about the last six years.

Figure 5: Margins with and without policy support and incentive as demand pull effect



Source: own calculation based on data e.g. from Fh-ISE (2013), Photon (1996-2013), BSW (2014)

In addition, Figure 5 (right) shows the pure demand pull effect of the demand pull instruments – the difference between the margin with and without support (incentive). The policy pull effect has been the strongest at the beginning of the support programs when there were only a few installations and weakened over time approaching zero (compared to retail electricity prices) when installations have grown. This illustration clearly depicts that only the **pull-effect** of a **policy** is insufficient to foster demand. Further incentives, such as returns or profits are needed to boost PV deployment.

But the growth – although small – of PV installations despite negative margins in the 90s also shows that financial **attractiveness** (high return) of an investment is certainly not always a necessary precondition for investment. This observation supports the assumption that other factors besides profitability affect demand for PV. These other factors could comprise idealistic thinking, combined effects between policies and economy and alternating significance/influence of instruments over time.

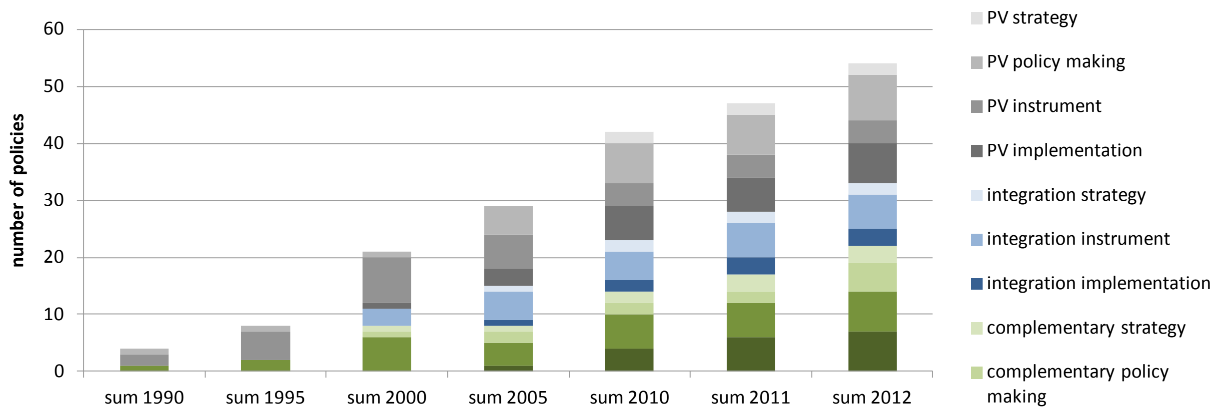
4.3 Evolvement and combination of policies

4.3.1 Number of policies

Commitment of policy makers based on the number of policies in force is illustrated in Figure 6. It reveals some interesting results: First, the composition of PV-related policies has changed over the years. At the beginning the PV-instruments played a central role but have decreased and policy making as well as implementation have gained in relevance. Complementary and integration instruments show a similar development: instruments were important at the beginning but the significance of implementation and policy making has increased over time. At the system level, this is a quite logic development. With increasing shares of RE or PV, integrations becomes more important. Complementary and integration policies can be interpreted as policies that strongly support the integration and the pursuit of RE or PV targets - a high share in electricity generation. Thus, a high number of complementary and integration policy underpin the political ambitions to promote PV (and RE) use.

However, the pure number of different policies (policy count) is only a weak measure to assess how strongly policy makers are committed to RE deployment. A low number of policies in force might not necessarily reflect a low commitment but just a very good policy design with no need for adjustments. In contrast, a high number of policies might be a signal for the complexity of an issue and a high need for adjustments. Finally, the policy count fails to account for the magnitude and direction of the policy impact; so it is a weak variable for depicting commitment.

Figure 6: Policies over time –count of policies in force



Source: own composition, based on divers data sources

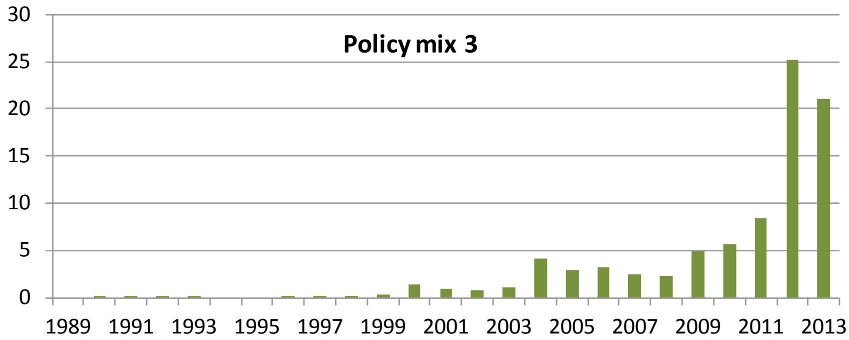
4.3.2 Combination of policies

The assumption that demand for PV is induced by expected profits bears two dimensions, a certainty dimension on future returns and profit dimension. While the profit dimension is captured by the margin or return, the certainty dimension depends on the long-term perspective of policies. The long term perspective of the supply industry is caught in this paper by the policy variable “target”.

RET deployment targets are considered an important policy that especially reflect long term planning or investment certainty. The policy target variable used here integrates the magnitude of targets and the long-term planning certainty. It signals planning certainty for manufacturers and suppliers (upstream) in the PV industry and is relevant for explaining investments or changes in the supply industry. It is less important for power generators, as the planning horizon for project development is much shorter. Thus a combination of target with a policy focused on technology suppliers under a long-term perspective is more meaningful than with a demand focused policy.

Combining the target variable with R&D support policy, which requires a long-term perspective, provides a policy mix variable addressing technology suppliers and combining the pull and push effect of both policies. It is depicted in Figure 7 (policy mix 3) and shows a growing push-pull-effect from 2000 onwards with a strong peak in 2012. The combined effect of these two policies before 2000 is rather low, signaling no incentive for technology providers to invest in R&D or technological exploration.

Figure 7: The policy mix – R&D support and targets



Source: own depiction based on policy variable target and R&D support

4.3.3 Other policies accompanying deployment of RE

Embedding policies in societal perception, awareness and thinking are part of the policy mix. Hitherto, political processes as well as societal discussions on energy policy have not yet been considered. To display the increasing awareness and priorities of society regarding energy and climate issues in Germany, the election results of the Green Party in Germany are used. This party put the promotion of alternative energies and the transition of the energy system as an important topic on their political agenda decades ago. Thus, their percentage of votes in federal and state elections promises to be an appropriate proxy for societal preferences regarding (renewable) energy policies. Simple correlation analyses between the share of the Green Party in Germany and the evolvement of the policy variables reveals significant (at 0.05) correlations between the policy variables target (0.78) and R&D spending (0.69). Similarly, positive and significant but moderate correlation between capacity growth (0.57) and the Green Party's share are observed. These findings underpin that social acceptance of policies and policy strategy as well as design and implementation of instruments show a parallel development over time. Moreover, policies seem to be legitimized by election results and are strongly embedded in society's perception, climate and energy objectives.

5 Conclusions

This paper deals with quantifying variables that capture renewable energy (RE) policies. For this purpose, the paper classifies RE policies into four groups: demand policies, supplier focused policies, technology push (R&D) policies and policy mix.

Supplier and R&D policies in monetary units have already been depicted and used for quantitative analysis in literature. They rely on official statistical data and are not further modified, while the variable for the demand pull instrument mix (e.g. margin) is a composite policy variable based on a mix of demand instruments in force over the last two decades. It represents a new policy variable that builds on the assumption that demand for PV modules is induced by expected profits. Eliminating the effect of technology costs on the margin displays the absolute pull-effect (incentive). It has been very strong at the beginning of the RE deployment support programs (1990). Besides demand pull instruments, target as a policy strategy promoting demand is employed as further policy demand pull variable. It shows a strong pull-effect in 2011/12. A combination of technology-push and demand-pull, the policy mix, mirrors the interaction of both policies and shows a very strong signal in 2012.

Nevertheless, the interaction of policy variables, or the policy mix is only captured rudimentarily. For example, the approach fails to explain growth in installations during negative margins, or low growth during times of strong demand pull-effects. Further, threshold values of policy variables, at which they start taking effect, are disregarded. Finally, R&D spending in combination with a strong market development might have a different focus and, hence, impact, than just technology push aspects that center more on research than on development or exploration. Subsequently, it cannot be concluded that there is an additive or multiplicative effect of policies, rather some policies are prerequisite; some have a large effect at a certain time, others less, or only in combination with others.

Regarding the evolvement of policies over time, correlations are a tool to recognize parallel developments of policy variables in magnitude and timing. Positive correlations between policy variables can be understood as a signal for consistency of policy makers' decisions.

Summing up, the objective to quantify key policies affecting market formation and knowledge generation is achieved. An instrument mix variable reflecting demand-pull-effect is elaborated. It shows absolute and relative, market and policy based pull-effects as well as pure policy induced pull-effects. But the development of an indicator to measure the impact of a policy mix is still in its infancies. Similarly, consistency in timing of policies is partly captured by correlations between policies. Commitment of policy makers is vaguely displayed by the increase of supportive and integrative policies while planning certainty or predictability is mirrored by the target variable.

6 References

Bafa (2014): Federal Office for Economic Affairs and Export Control; Infrmation on GRW and EFRE resources

Barbieri, E., Di Tommaso, M., R., Bonnini, S., (2012): Industrial development policies and performances in Southern China: Beyond the specialised industrial cluster program ; China Economic Review 23 (2012) 613-625

Benhassine, N. and Raballand, G.(2009): Beyond ideological cleavages: A unifying framework for industrial policies and other public interventions; Economic Systems 33 (2009) 293-309

BMWi (2013): diverse sources of the German Federal Ministry for Economy and Energy, http://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/erneuerbare_energien_in_zahlen.html

Brand B., Zingerle, J. (2010): The renewable energy targets of the Maghreb countries: Impact on electricity supply and conventional power markets. *Energy policy* (2010), doi 10, 1016/j.enpol.2010.10.010

Breitschopf B., (2015): Impacts of policies on market formation and competitiveness – The case of the PV industry in Germany; Working Paper Sustainability and Innovation No. S 06/2015 Fraunhofer-ISI

Breznitz, D.; (2007): Industrial R&D as a national policy : horizontal technology policies and industry-state co-evolution in the growth of the Israeli software industry ; Research Policy 36 (2007) 1465-1482

BSW Bundesverband Solarwirtschaft (2011, 2012, 2014, 2014): Statistikpapiere „Photovoltaik" http://www.solarwirtschaft.de/presse-mediathek/marktdaten.html

Bundesförderdatenbank, download Januar 2013; http://www.foerderdatenbank.de/Foerder-DB/Navigation/Foerderrecherche/suche.html?get=d3eae3ce331e468c0274329d14467def;search;index&typ=dt

Bürer, M. J., Wüstenhagen, R., (2009): Which renewable energy policy is a venture capitalist´s best friend? Empiriacal evidence from a survey of international cleantech investors, *Energy Policy*, (2009)37, 4997-5006

Butler, L., Neuhoff, K., (2008): Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. *ScienceDirect*, (2008)33, 1854-1867

Del Río, P., Bleda, M., (2012): Comparing the innovation effects of support schemes for renewable energy technologies: A function of innovation approach. *Energy Policy,* (2012)50, 272-282

Dewald. U. (2011): Energieversorgung im Wandel – Marktformierung im deutsche Phtotvoltaik-Innovationssystem, Band 51, Wirtschaftsgeographie

Dinica, V. (2006),: Support systems for the diffusion of renewable energy technologies an investor perspective. *Energy Policy*, (2006)34, 461-480

DIW, Forschungszentrum Jülich, Fh-ISI, Öko-Institut Berlin (1997): Politikszenarien für den Klimaschutz, Band 1 – Untersuchung im Auftrag des Umweltbundesamtes ISBN 3-89336-215-0

Fh-ISE (2013): Studie Stromgestehungskosten erneuerbarer Energien, C. Kost, Th. Schlegel. J. Thompsen, S. Nold, J. Mayer Version 20. Mai 2012

Grau, T., Huo, M., Neuhoff, K. (2012): Survey of photovoltaic industry and policy in Germany and China. *Energy Policy,* (2012)51, 20-37

Hekkert, M., Negro, S., (2009): Functions of innovation systems as a framework to understand sustainable technological change: empirical evidence from earlier claims. *Technological Forecasting & Social change,* (2009)76, 584-594

Hoppmann, J., Peters, M., Schneider, M., Hoffmann, V.H.,(2013): The two faces of market support – how deployment policies affect technological exploration and exploitation in the solar photovoltaic industry. *Research Policy,* (2013)42, 989-1003

ISI et al. (2014): Monitoring der Kosten- und Nutzenwirkungen des Ausbaus erneuerbarer Energien im Jahr 2013; Fraunhofer ISI: B. Breitschopf, M. Klobasa, L.Sievers, F. Sensfuß, J. Steinbach; GWS: U. Lehr; DIW: J. Diekmann; IZES: J. Horst. http://www.impres-projekt.de/impres-en/content/arbeitspakete/ap5/ bilanzierung-wirkungen.php

Jacobsson, S., Lauber, V., (2006). The policis and policy of energy system transformation – explaining the German diffusion of renewable energy technology. *Energy Policy,* (2006)34, 256-276

Jenner, S. Groba, F., Indvik, F., (2013): Assessing the strength and effectiveness of renewabel electricity feed-in tariffs in the European Union countries. *Energy Policy,* (2013)52, 385-401

Johnstone, N., Hascic, I., Popp, D., (2008). Renewable energy policies and technological innovations: Evidence based on patent counts. *NBER Working Paper,* Working Paper 13760, January 2008

Khammas, A., (2013): Buch der Synergie, Teil C, www.buch-der-synergie.de, download Juni 2013

Kranzl, L., Hummel, M., Müller, A., Steinbach, J. (2013): Renewable heating: Perspectives and the impact of policy instruments. *Energy Policy*, (2013)59, 44-58

Laforet, S., (2008). Size, strategic and market orientation affects on innovation. *Journal of Business Research,* (2008) 61, 753-764

Lehr, U., Breitschopf, B., Vidican, G., (2014): RE Value Policies: Policy Instruments to Support Renewable Energy Industrial Value Chain Development; IEA Implementing Agreement on

Lewis, J. I., Wiser, R. H., (2007): Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. *Energy Policy*, (2007)35, 1844-1857

Lipp, J. (2007): Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. *Energy Policy*, (2007)35, 5482-5495

Lund, P.D., (2009): Effects of energy policies on industry expansion in renewable energy. *Renewable Energy,* (2009)34, 53-64

Masini, A., Menichetti, E., (2012): The impact of behavioural factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. *Energy Policy,* (2012)40, 28-28

Peters, M., Schneider, M., Griesshaber, T., Hoffmann V. H., (2012): The impact of technology-push and demand-pull policies matter? *Research Policy*, (2012)41, 1296-1308

Photon 1996 - 2013; Journal for solar power

Rennings, K., (2000): Redefining innovation – eco-innovation research and the contribution from ecological economics. *Ecological Economics,* (2000)32, 219-332

Rio del P. and Bleda, M. (2012): Comparing the innovation effects of support schemes for renewable energy technologies: A function of innovation approach. *Energy Policy,*(2012)/50, pp 272-282

Rogge, K.S. and Reichardt, K. (2013): *T*owards a more comprehensive policy mix conceptualization for technological environmental change: a literature synthesis. Working Papers Sustainability and Innovation No. 3/2013. Karlsruhe: Fraunhofer ISI. Online available at http://www.isi.fraunhofer.de/isi-media/docs/e-x/de/working-papers-sustainability-and-innovation/WP03-2013_policy-mix-conceptualization.pdf

Sovacool, B. K., (2010). A comparative analysis of renewable electricity support mechanisms for Southeast Asia. *Energy*, (2010)35, 1779-1793

Stokes, L. C., (2013). The politics of renewable energy policies: The case of feed-in tariffs in Ontario, Canada. *Energy Policy*, (2013)56, 490-500

White, W., Lunnan, A., Nybakk, E., Kulisic, B. (2013): The role of governments in renewable energy: The importance of policy consistency. *SciVerse ScienceDirect*, (2013), 1-9

Wüstenhagen, R., Bilharz, M. (2004): Green energy market development in Germany: effective public policy and emerging customer demand. *Energy Policy*, (2006)

Yin and Powers H. Yin, N. Powers (2009): Do state renewable portfolio standards promote in-state renewable generation? Energy Policy, 38 (2) (2009), pp. 1140–1149

A.1 Annex

A-Table 1: Examples for policy mix (incomplete list)

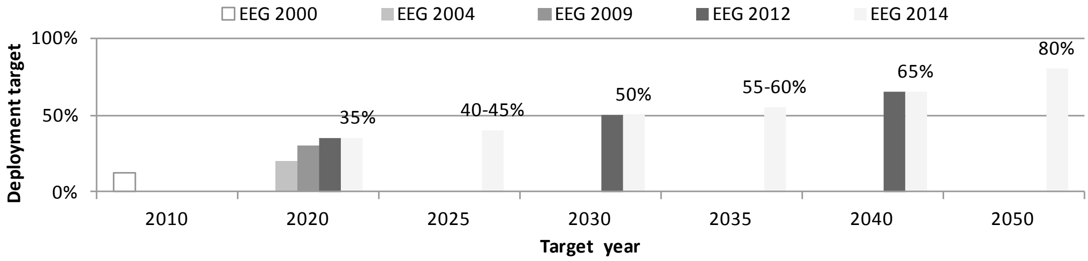
Name	Policy mix
1.000-Dächer-Programm (1991-1995)	PV instrument
100.000-Dächer-Programm	PV instrument
Abschaltverordnung (VO über abschaltbare Lasten)	integration instrument
AGEE Stat	PV implementation
Anreizregulierungsverordnung	integration implementation
Ausführungsverordnung für Ausgleichsmechanismus	PV implementation
AusgleichsmechanismusVO	PV implementation
Biokraftstoff-Nachhaltigkeitsverordnung	complementary implementation
Biomassestrom-Nachhaltigkeitsverordnung	complementary implementation
BiomasseVerordnung	complementary implementation
BMU Umweltinnovationsprogramm	integration instrument
Solarkampagne 2000 (BAUM, DBU, IHK)	complementary instrument
Solar -na klar! (DBU, BMWi, BAUM)	complementary instrument
DtA-Programme	complementary instrument
EEG 2000	PV instrument
EEG 2004	PV instrument
EEG 2009	PV instrument
EEG 2012	PV instrument
EEG-Clearingstelle	PV implementation
EEWärmeG	complementary instrument
EEWärmeG Baden-Württemberg	complementary instrument
Eigenheimzulage	complementary instrument
KfW-Programm "Solarstrom erzeugen"	PV instrument
Energiewirtschaftliche Vorschriften	integration implementation
Energiewirtschaftsgesetz (EnWG)	integration instrument
EU Richtlinie Biokraftstoffe 2003/30/EG	complementary instrument
EU Richtlinie EE, EC 2009/28/EG	PV instrument
EU Richtlinie Strom 2001/77/EG	PV instrument
EU Court of Justis Decision on FIT	PV implementation
Europarechtsanpassungsgesetz EE (EAG EE)	complementary implementation
Gesetz zum Emissionshandel THG	integration instrument
ETS EU	integration instrument
Herkunfstsnachweisverordnung	complementary implementation
Herkunftsnachweis-Durchführungsverordnung	complementary implementation
KfW-Umweltprogramm	PV instrument
KWK_Vorschaltgesetz	complementary instrument
KWKG	complementary instrument

KWK-Impulsprogramm	complementary instrument
KWK-Investitionsförderung (Impulsprogramm)	complementary instrument
ManagementprämienVO	PV implementation
MAP	complementary instrument
KfW Sonderprogramm PV	PV instrument
KfW Programm Erneuerbare Energie (Standard)	PV instrument
KfW Programm Erneuerbare Energie (Premium)	complementary instrument
ERP Umwelt-Energiesparprogramm	PV instrument
Nationaler Allokationsplan	integration strategy
Nationaler Aktionsplan	PV strategy
SET Plan EU	integration strategy
Road Map EU	complementary strategy
Leitstudie	PV strategy
…	…

A-Table 2: Assumptions for LCOE e.g. in 1990

Example for PV roof-top plant (1-10 kW, Si)	
Year	1990
System price/kW in €	14000
Operation and maintenance costs, in %	4
life span of PV plant	20
Discount factor in %	3,5%
Solar radiation, in kWh/m²	1055
Module surface [m²]	7,5
Annual yield reduction, in %	1,00%
Alinement of modules, in %	100,00%
Efficiency of modul in %	11
Efficiency of inverter in %	85

A-Figure 1: RE Deployment targets in Germany



Source: own depiction

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