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Measuring policy-driven innovation in energy efficiency

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Abstract

Innovation plays a crucial role in the transition towards a sustainable energy system. In order to simultaneously achieve the objectives of sustainability, energy security and competitiveness of the European economy, various energy policies are active. In recent years, the effect of energy policies on both technological and non-organisational innovations has gained interest. However, the complexity of the systems renders it difficult to disentangle the innovation effects of energy and innovation policies. Here, we outline a unifying framework based on the notion of technological innovation systems. It distinguishes between different phases of the innovation process, actors and functions in the innovation systems and allows studying the effects of policies on these in a systematic fashion. We apply our framework to case studies from the field of energy efficiency in industry for a technological and organisational innovation. Our results help to organise previous research findings and to identify gaps for further studies.

Keywords: energy efficiency, innovation, policy measures, technology diffusion

1 Introduction

Innovation is generally expected to play a crucial role in the transition towards a sustainable energy system. In order to simultaneously achieve the objectives of sustainability, energy security and competitiveness of the European economy, innovation both on the demand and supply side are required (Foxon et al. 2008; Wilson et al. 2012). The development and diffusion of innovations to mitigate climate change require policy support. For such eco-innovations a large-scale diffusion will generally not happen through unregulated markets (van den Bergh 2013). In recent years, the role of energy policy to support innovation has gained increasing importance both within European energy policy and in the academic debate (Schiellerup and Atanasiu 2011; Blind 2012; Edler 2013; Wilson et al. 2012).

A successful policy support for innovation in clean energy requires an understanding of the innovation system and a set of indicators to monitor the policies' impact. In innovation theory, the complexity and non-linearity of innovation processes has been recognized for a long time, and innovations are studied in a systemic context entitled innovation system (Freeman 1987; Lundvall 1992). Many of the existing quantitative studies of the innovation impact of energy efficiency policy (see e.g. Noailly and Batrakova 2010; Kammerer 2009; Rexhäuser and Rammer 2011; Costantini and Crespi 2014) mainly focus on patents as an indicator of innovation, thus reflecting predominantly the effect of policy strategies on the invention stage of the innovation process. On the other hand, many of the studies that take a systemic perspective (Ruby 2015) are often based on qualitative approaches (Ruby 2015; Kiss et al. 2013; Foxon et al. 2005).

When investigating the effect of energy efficiency policy on innovation, it is important to observe that there is a so-called energy efficiency gap between the actual uptake of energy efficiency innovations and the economically optimal level (Jaffe and Stavins 1994; Allcott and Greenstone 2012). On the demand side, policy measures to promote innovation in energy efficiency can address the barriers and market imperfections that prevent the uptake of energy efficiency innovations. Such barriers include information asymmetries, split incentives, lack of interaction between user and producer, lack of awareness, lack of capabilities to define needs or respond to innovation (Edler 2013). In order to capture the effect of policy on energy efficiency innovations it is therefore essential to study the impact of energy policy measures using an approach that goes beyond patent analysis and comprises the development and in particular also the phases of diffusion of innovations as well as the relevant actors.

Thus, the overall aim of this working paper is to connect the theory of diffusion of innovations with the technological innovation system (TIS) approach and to develop a methodological approach which considers the three dimensions (1) innovation phase, (2) TIS function and (3) relevant actor. This paper illustrates the approach by applying it to two case studies from the field of energy efficiency in industry for a technological and organisational innovation. The paper is organised as follows. We provide a brief background on related work and the TIS concept in section 2. We introduce and discuss our methodological extension in section 3 which is followed by empirical illustrations in section 4. We close with conclusions and an outlook in section 5.

2 Background: Related work and the TIS concept

2.1 Related work and concepts

The innovation impact of environmental policy has been studied rather extensively in the context of the Porter hypothesis (e.g. Kemp and Pontoglio 2011). However, for energy efficiency the impact of energy and innovation policy on the diffusion of technological and organizational innovations has been studied only marginally from an innovation system perspective (e.g. Ruby 2015). In order to measure the innovation impact of energy and innovation policy a disaggregated approach is needed, covering a systemic comprehension of the innovation system as well as a comprehensive measuring approach including apart from technological innovation also financial, organizational and service innovations in the energy sector. However, these innovations can be more difficult to capture.

Research and innovation is a multidimensional, knowledge-generating process, for which the input, the activities themselves as well as the output are decisive. Simultaneously, policy can shape and control the development process of innovations with different instruments at different stages of the innovation process. For this purpose transparency and knowledge about different mechanisms induced by policy instruments are crucial. The existing empirical research is often based on output indicators (sometimes in conjunction with input indicators). Typical indicators to measure the technological performance are e.g. patents, R&D expenses or scientific publications (Smith 2005, OECD 2005). Arundel and Kemp (2009) for example try to develop an approach for measuring environmental innovation based on input-, indirectly output- and output-oriented indicators (see Table 1).

However, these indicators do typically neither capture non-technological innovations (such as organizational and service innovations) nor indirect effects (such as e.g. new actors, new business models, new forms of cooperation and interaction) which gain in importance. Existing research on innovations in the energy system often analyzes fragments at an aggregated level. For a disaggregated monitoring a systemic understanding and innovation measurement approach is required which considers technical product and process innovations as well as service and organizational innovations simultaneously. Previous empirically applied approaches do not consider the different phases of the diffusion process as well as the interaction and dynamics of the various actors in the innovation system in their entirety.

Table 1: Input and output-based indicators

Input indicators	• Research and development (R&D) expenditures, R&D personnel, and innovation expenditures (including investment in intangibles such as design expenditures and software and marketing costs) • Learning processes: training, market research, etc. • Cross-organizational cooperation and research and innovation networks (eg. Learning energy efficiency networks) • Non-R&D Input: Design, techn. Development, Education & Training
Output indicators (indirectly)	• Patents and scientific publications • Changes in product mix, market diffusion indicators
Output indicators	• Learning curves / learning effects: new / improved products, new / improved processes or organizational processes • Use of new distribution channels

Source: Arundel and Kemp (2009)

2.2 The TIS concept

In terms of the definition and comprehension of the concept "innovation system" this paper focuses on the technological innovation systems (TIS) approach which could thanks to its functional structure provide valuable insights in the dynamic of the energy efficiency innovation system (see e.g. Bergek et al. 2008; Hekkert and Negro 2009). The following table briefly describes the different functions and their relevance to the innovation system.

In the recent literature regarding the energy system, the TIS approach has mainly been adapted to the sector of renewable energies with the aim to analyze among others the role of the policy mix for TIS functioning and performance (e.g. Reichardt et al. 2016 for the case of offshore-wind energy, Negro et al. 2007 for the case of biomass or Bergek et al. 2008 for the case of solar cells), but there is less literature focusing energy efficiency, in particular in industry. As the TIS approach is very well suited to map innovation processes in a decentralized manner we base our measurement framework on this approach. With our paper we aim to contribute to the above mentioned research gap. The following chapter describes our measurement approach and extends the TIS approach for the energy efficiency innovation system when developing the measuring concept to allow for explicitly including the time and actors' perspective. Later we empirically apply this approach to the case of energy management systems and energy efficient electric motors.

Table 2: Overview of TIS functions

TIS Function	Description
F1 & F2 knowledge generation and diffusion	"heart of a TIS", knowledge and learning (e.g. academic and firm R&D, but also activities such as learning by doing, learning by using or learning by imitation); knowledge diffusion is a precondition for learning
F3 Influence on the direction of search	Interactive process of exchanging ideas between technology producers, users and other actors (e.g. incentives from changing factors and product prices, expectations, regulations and policy, demand from leading customers, etc.)
F4 Entrepreneurial experimentation	R&D, government policies, competitors, markets, etc., Uncertainty in terms of technologies, applications and markets is fundamental for the TIS (in all phases); focus on how the potential of new knowledge, networks and markets are turned into concrete actions to generate, realise and take advantage of new business opportunities
F5 Market formation	E.g. formation of niche markets, create (temporary) competitiveness through regulations; in successful TIS mass markets may evolve
F6 Resource mobilization	Resources as a basic input to all activities (mobilize human and financial capital and complementary assets such as e.g. services, network infrastructure, etc.)
F7 Legitimation	Prerequisite for the formation of new industries; the new technology and its components need to be considered appropriate and desirable in relation to relevant institutions and actors; organizations and institutions could help the TIS to overcome "liability of newness"; TIS seldom emerges in a vacuum, but need to compete with established TIS

Source: based on Hekkert et al. (2007); Bergek et al. (2008)

3 Methodological extension of the TIS approach to measure policy effects

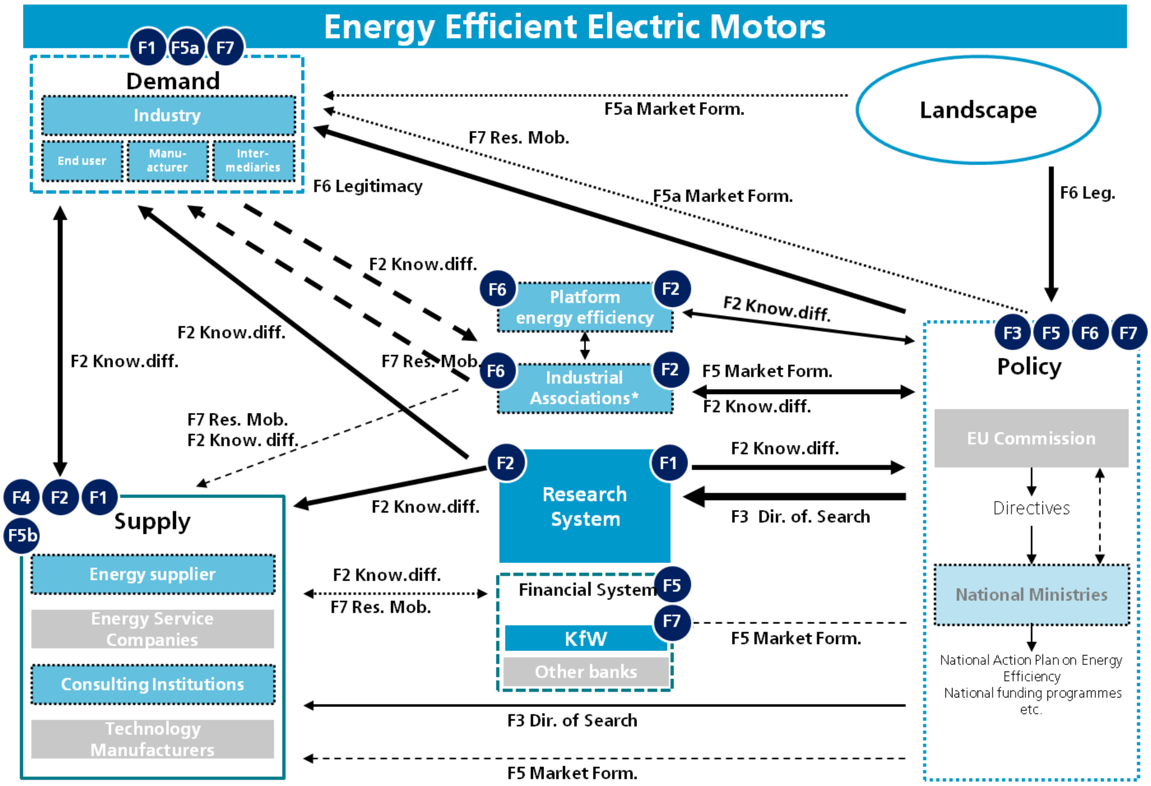
Analyzing the functional patterns of the TIS brings new findings regarding how the TIS is functioning, but in order to assess the system functionality, the life-cycle of an innovation and the relevance of the different actors at different points of time the following dimensions have to be taken into account. Hence the proposed measurement framework and indicator-set considers the following three dimensions:

- Phase of the innovation process (see Figure 2),
- Relevant actor (see Figure 1),
- TIS function (see Table 2),

To adapt and extent the classical TIS concept for measuring innovation in the innovation system of energy efficient technologies including organizational innovation, several specific refinements were made. The concept of functions as key processes of an innovation system as described by Bergek et al. (2007) is carried over to this approach and these functions were at first assigned to the relevant actors. Figure 1 gives a schematic overview about the innovation system for electric motors in industry which consists inter alia of demand and supply-side actors, policy, financial system, research system, associations and platforms. If a TIS function is not fulfilled adequately by an actor the arrows and lines are dotted. A detailed description of the TIS regarding energy efficient electric motors is given in Köhler et al. (2016).

In a second step the TIS functions were assigned to a typical chronological sequence of phases of innovation processes as proposed by Meyer-Krahmer and Dreher (2004), which usually takes the form of a logistic S-curve (see Figure 2, Rogers 2003). For each combination of the dimensions (1) phase, (2) TIS function and (3) relevant actor one or several indicators can be developed (for an overview see Appendix). However, not every combination carries adequate information depending on the issue investigated. To allow a suitable measurement of the interaction of actors between each other, e.g. the influence of certain policies on other actors like manufacturers or research, a differentiation of functions and their specific importance in the different phases is necessary. The relevance of each function in the different phases of the innovation process is highlighted in green (high relevance) and light green (low relevance) in Figure 2.

Figure 1: Schematic illustration of the TIS for energy efficient electric motors



* BDI, ZVEI, DIHK, VDMA, VCI, DENEFF, ZDH, etc.

F1: Knowledge generation
F2: Knowledge diffusion
F3: Influence on direction of search
F4: Entrepreneurial experimentation

F5: Market formation; F5a demand; F5b: supply
F6: Legitimacy
F7: Resource mobilisation

Source: Köhler et al. (2016)[1]

To measure the performance of different functions in combination with the actors of an innovation system in their main phase of relevance several indicators specific to the technological or organizational innovation investigated are proposed. Table 3 shows several examples of possible indicators for different combinations of dimensions.

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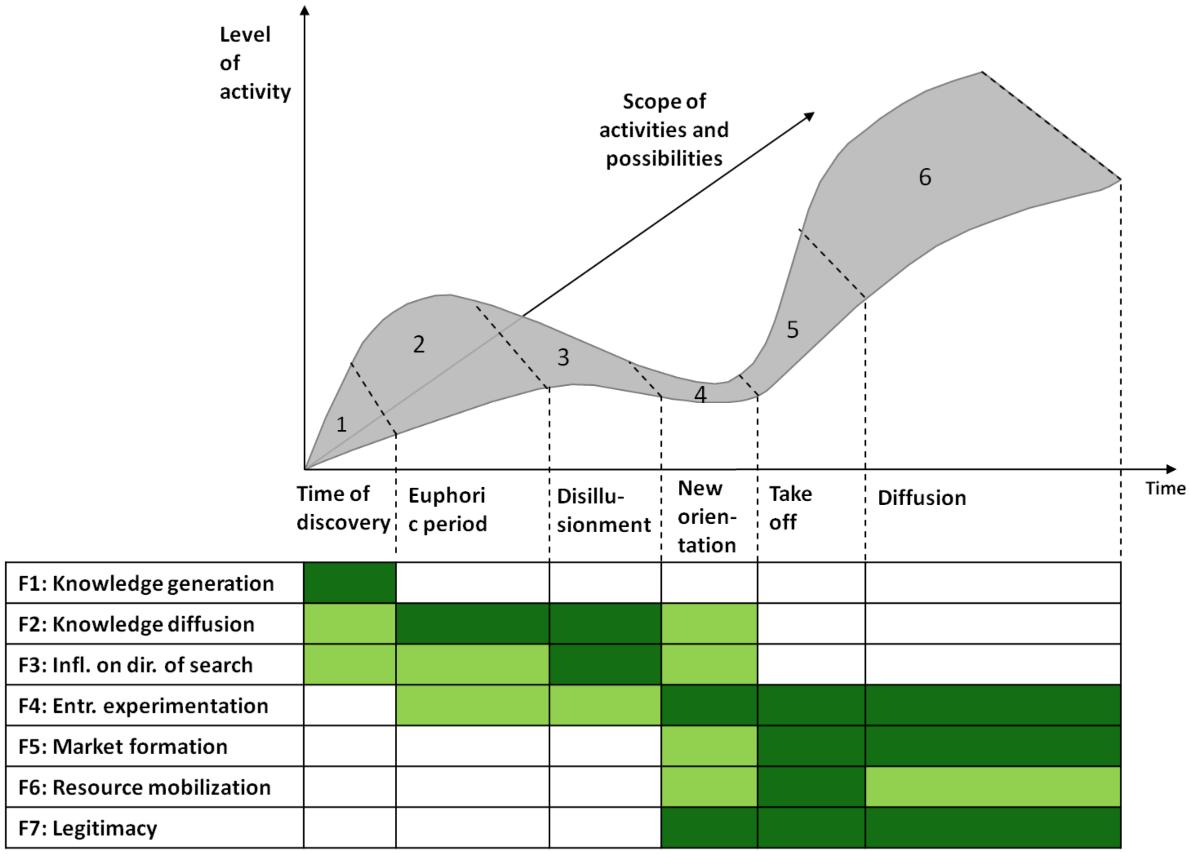
[1] Please note that the assignment of TIS functions to the numbers F1 – F7 in the paper from Köhler et al. 2016 slightly differs from the numbers in this paper. Nevertheless, the TIS functions used are the same.

Figure 2: Phases of the innovation process and relevant TIS functions



	Time of discovery	Euphoric period	Disillu-sionment	New orien-tation	Take off	Diffusion
F1: Knowledge generation	🟩					
F2: Knowledge diffusion	▨	🟩	🟩	▨		
F3: Infl. on dir. of search	▨	▨	🟩	▨		
F4: Entr. experimentation		▨	▨	🟩	🟩	🟩
F5: Market formation				▨	🟩	🟩
F6: Resource mobilization				▨	🟩	▨
F7: Legitimacy				🟩	🟩	🟩

Source: extension of Jochem et al. (2009)

As an example for the phase *euphoric period* (see Figure 2) with the actor *research system* (see Figure 1) and the TIS function *knowledge diffusion* (see table 1) the examination of the concentration of patent activities in terms of energy efficiency innovations by means of the Herfindahl index to different research institutions could be a suitable indicator (see Table 3).

Table 3: Schematic overview of three-dimensional measuring concept

Phase	**Actor**	**TIS Function**	**Data**	**Indicator**	**Measurement of policy influence**
Discovery	Research system	Knowledge generation	Patent data	Relative patent advantage (RPA)	Comparison RPA in countries with different policies
Euphoric period	Research system	Knowledge diffusion	Patent data	Concentration of patents on certain research institutions Herfindahl index (*H*)	Development of *H* over time in different countries with different policy conditions
Disillusionment	Policy	Influence on direction of research	R&D budgets	Relative share of a certain technology	Relative shares of R&D budgets in countries with different (energy) policies
New orientation	Supply	Entrepreneurial experimentation	Business registers	Insolvencies / establishment of companies in relevant branches	Comparison of different countries and technologies
Take off	Supply	Resource mobilization	Venture capital statistics	Financial capital investments in relevant branches	Development over time in different countries with different policy conditions
Take off and Diffusion	Supply	Market formation	Sales figures	Sales figures of certain technologies in time course	Comparison of countries with different market conditions
Diffusion	Demand	Legitimacy	Ownership rates	Diffusion of products in the market	Comparison of countries with different market conditions or policies

Source: own compilation

Table 3 shows some exemplary combinations that are relevant for the investigation of the impact of energy efficiency policy on the diffusion of innovations. Obviously various further combinations for analyses resulting from this grid are imaginable, but only some of the combinations are interesting for the investigation of the impact of energy efficiency policy on the diffusion of innovations. We will concretize possible case studies in more detail below and apply the measurement approach to two case studies; one organizational innovation – energy management systems and one technological innovation – energy efficient electric motors.

In summary, the outlined measurement concept provides a scheme for systematic connection between policies and the innovation system in different phases of the innovation process and diffusion. For a chosen combination of innovation process phase, actor and TIS function an empirical analysis is possible. To this end, statistical tests can be applied to indicators on empirical data. The large variety of statistical tools and data together with the complexity of the natural world render this a complex field of research. More specifically, one can analyse correlations, regression models and other statistical tools. No general suggestions can be made on the appropriate tools since the choice of method depends on individual research question and data.

Causal effects and the possibility to steer the innovation process by policies are of special interest. Econometrics has developed a set of methods to study causal effects (e.g. instrumental variables, Granger causality and Rubin's model of causality – see Heckman 2008; Granger 1969; Wooldridge 2010) which can be used to study the effect of policies on innovation systems if sufficient data is available. Apart from quantitative methods, interviews and discussions with stakeholders can yield valuable insights into the effect of policies on the innovation system. For different combinations of phases, actors, and functions the most suitable approach differs, depending on data availability and research question.

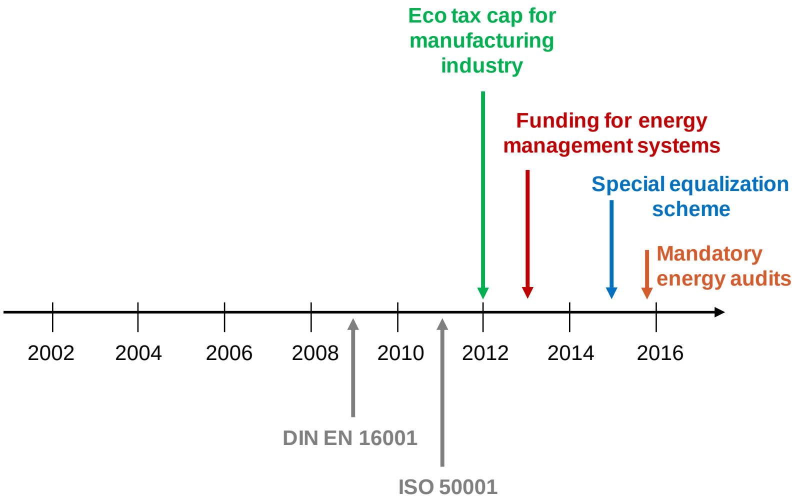
4 Empirical results

This part of the paper empirically applies the measuring concept on two different case studies in order to investigate the policy impact on the diffusion of energy efficiency innovations in the industrial sector. The first case study aims to investigate the impact of energy efficiency policies on the diffusion of energy management systems in industrial companies whereas the second case study focuses on a technological innovation and investigates the effect of regulation on innovation in Electric Motor Driven Systems (EMDS).

4.1 Energy management schemes

In the case of energy efficiency the availability of technology is mainly given. However, due to several barriers the diffusion of these technologies in the market is rather slow (e.g. Sorrell et al. 2004) which is the reason why policy instruments mainly tend to address the later stages of the innovation process. Organizational innovations seem to be a favourable factor for the diffusion of technical innovations in some cases. Brunke et al. (2014) (for the iron and steel industry) and Böttcher and Müller (2014) (for the automotive industry) find for example a significant effect between the introduction of an energy management system and the adoption of energy saving measures in companies. Especially in the field of energy efficiency, the assumption could be made that organizational and service innovations are often related to technological innovations, such as e.g. in the case of contracting or energy efficiency networks. In the present section, we study the diffusion of an organisational innovation connected to energy efficiency: energy management systems. Energy management systems are a systematic way of analysing the procurement, conversion and use of energy within an organisation under environmental and economic objectives (VDI Guideline 4602). They have been standardised as Norm EN 16001 until 2011 and as ISO 50001 since then. Since 2012, the German government established different policy instruments which aim at the promotion of the implementation of energy management systems in the German industry (for an overview see Table 4). For this purpose initially in 2012 the *Eco tax cap for manufacturing industry* was established (Federal Ministry for Economic Affairs and Energy 2013; see Figure 3). Companies that are granted tax caps have to provide proof that an energy management system has been implemented in the respective year when the company requests the tax redemption. Small and medium-sized companies are allowed to implement an alternative system (e.g. an audit in line with DIN EN 16247-1). The amendment of this law came into force on 9th November 2012. However, this is not mandatory for companies; the tax redemption is available upon request to companies and enables the redemption of up to 90% of electricity and/or energy taxes paid).[2] One year later in 2013, the Federal Ministry for Economy and Energy launched a *funding programme* which financially supports the certification of energy management systems for companies (Federal Ministry for Economic Affairs and Energy 2015a).[3]

Figure 3: Policy instruments and certification schemes for energy management systems



Source: own compilation

Additionally, the German government decided to promote energy management systems in the course of the *Special Equalization Scheme* in the German Renewable Energy Sources Act (EEG). According to this law, the EEG surcharge can be limited for electricity-intensive companies and rail operators by BAFA upon request.[4] As of 2015 applicants have to operate a certified energy or environmental management system (in line with DIN EN ISO 50001, formerly 16001 or EMAS) to get the tax redemption. Companies with an electricity consumption of less than 5 GWh can operate alternative systems (e.g. according to DIN EN 16247-1) that improve energy efficiency. The fourth policy instrument implemented recently which aims to promote the implementation of

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[2] A further requirement which is directly connected to this mechanism is the fact that the energy intensity of the manufacturing industry as a whole has to be continuously reduced. The legal targets for this energy intensity are 1.3% annually for the period from 2013 to 2015 and 1.35% for 2016. Based on a third-party monitoring report, the German government will investigate whether the industries that benefit from the tax caps have met the necessary legal requirements for reducing energy intensity.

[3] Companies which already requested tax redemptions according to the Special Equalization Scheme or the Eco tax cap for the manufacturing industry are not eligible for this funding programme.

[4] Beneficiaries pay the full EEG surcharge for the first GWh and then 15% of the EEG surcharge for every kilowatt hour of electricity they consume above this. This burden is limited to a maximum of 4% of the respective enterprise's gross value added or, in the case of enterprises with an electricity-cost intensity of 20% or more, a maximum of 0.5% (cap/super-cap in the EU's Guidelines on State aid for environ-mental protection and energy).

energy management systems is the regulation for large companies (defined as non-SMEs) to implement *mandatory energy audits* (Federal Office for Economic Affairs and Export Control 2015; Rohde and Eichhammer 2016). To be compliant obligated companies have also the possibility to implement a certified energy management system according to ISO 50001 or an environmental management system in line with EMAS until 31st December 2016 (Article 8 (3) EDL-G).

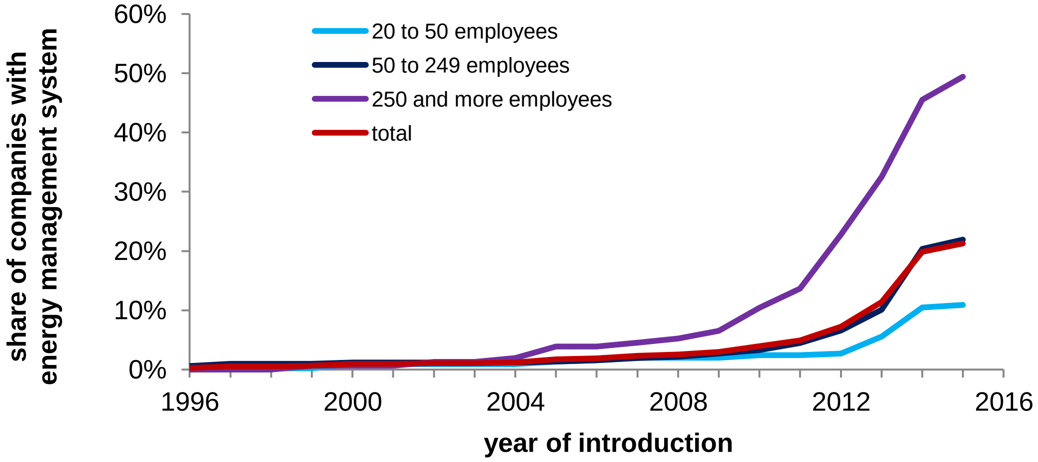
Table 4: Overview of policy instruments promoting energy management systems

Policy incentive	Legislative basis	Relevance with regard to energy management systems
Eco tax cap for manufacturing industry	Electricity tax law (§ 10 StromStG and Energy tax law (§ 55 EnergieStG) in combination with the regulation Spitzenausgleich-Effizienzsystemverordnung (SpaEfV)	Companies that are granted tax caps have to provide proof that an energy management system will have been introduced by the end of 2015 (for SMEs an alternative system is possible).
Special equalization scheme	§ 64 (1) No. 3 EEG 2014	As a prerequisite to obtaining the reduction of the renewables surcharge, applicants have to operate a certified energy or environmental management system; companies with an electricity consumption of less than 5 GWh can operate alternative systems
Funding scheme for energy management systems	Directive on the promotion of energy management systems	Funding available for the implementation of an energy management system
Mandatory energy audits	Law on Energy Services and other Energy Efficiency Measures (§§ 8-8d EDL-G)	Compliance to EDL-G is also possible by the introduction of an energy management system

Source: own compilation

To study the impact of the above mentioned policy instruments on the share of companies that have implemented an energy management system we use data from the European Manufacturing Survey (Fraunhofer ISI 2015) which is a representative survey of the German manufacturing industry from 1996 to 2015. Figure 4 illustrates the time evolution of the share of companies which implemented an energy management system between 1996 and 2015 divided by the size of the companies. Apparently large companies (≥ 250 employees) form the largest group of adopters.

Figure 4: Diffusion of energy management systems in companies from 1996 to 2015[5]



Source: data Fraunhofer ISI (2015)

The overall energy costs for the German manufacturing industry (total energy costs divided by total energy consumption according to Federal Ministry for Economic Affairs and Energy 2015b) is shown below in Figure 5. Out methodology follows the work of Clerides and Zachariadis (2008). We perform a regression of the overall energy costs and presence of the incentive on the share of companies that have implemented an energy management system.

$$\mathrm{EMS}_t = \beta_1 \mathrm{EnergyCost}_t + \beta_2 \mathrm{Incentive}_t + \beta_3 \mathrm{Trend}_t + \beta_0$$

Here, Trend denotes an additional time trend variable that uses the natural logarithm of the year.

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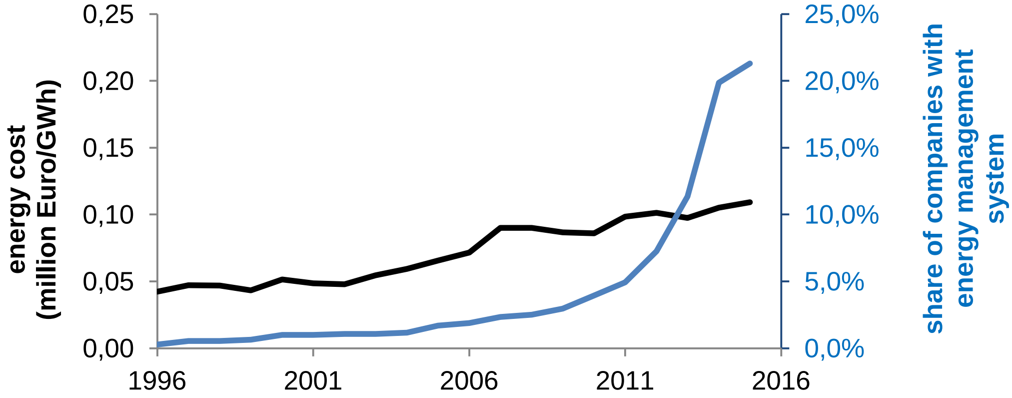
[5] The data collection of the European Manufacturing Survey took place from February to July 2015. Therefore the share of energy management systems for 2015 does not include data for the whole year and thus is preliminary.

Figure 5: Share of companies with energy management scheme and energy costs for the German industry



Source: data Fraunhofer ISI (2015), Federal Ministry for Economic Affairs and Energy (2015b[6])

The regression results are summarised in the following table. Both the time trend and the incentive have a significantly (at 0.1% level) positive effect on the share of companies that have implemented an energy management system.

Table 5: Regression of companies with energy management system

	Estimate	Std. Error	t value
(Intercept)	-43.7	66.4	-0.66
Trend	5.76	8.73	0.66
Energy costs	0.09	1.05	0.09
Incentive	0.10***	0.02	4.59

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05; N = 17; F(3,13)= 25.2; P-value = 3e-06; R^2 = 0.83; Adj-R^2 = 0.79

Source: own compilation

However, the regression results come with some uncertainty. The observed shares of companies are not exactly normally distributed. Furthermore, it has been argued that the analysis in terms of cross-sectional data neglects the time ordering of the observations. The latter would lead to noteworthy autocorrelation of the residuals. We performed a Box-Cox test to analyse whether the dependent variable should be transformed. The maximum likelihood estimate for the lambda parameters peaks at lambda = 0 (with 95% confidence interval [0, 0.1]) suggesting not to transform the dependent variable. Additionally, autocorrelation in the residuals can be tested with linear regression or a Durbin-Watson test. The former finds no significant connection between the

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[6] Due to the lack of official statistics, the energy costs for 2014 and 2015 have been linearly extrapolated from previous years.

residual and lagged residual and the latter rejects the null hypothesis of no autocorrelation for a regression on the share of companies at 5% level. The regression results for with the inclusion of a lagged dependent variable are similar to the results stated in the table above (positive impact of the incentive at 5% level).

In summary, a financial incentive to use energy management systems induced by the different policy instruments has increased the diffusion of energy management systems in the German manufacturing industry in the recent years.

4.2 Energy efficient electric motors

Electric motor driven systems (EMDS) represent the single largest electrical end-use after lighting, accounting for between 43 and 46% of the global electricity consumption and 69% of industrial electricity consumption (Waide and Brunner 2011). Thus, innovation regarding their energy efficiency offers enormous energy saving potentials.

Our study addresses the impact of the minimum energy performance standards (MEPS) set by the EU-Ecodesign directive on innovation in efficient electric motors. The Ecodesign directive specifies ecodesign requirements on energy-related products. Ecodesign requirements are minimum requirements that the products need to fulfill if they are to display the CE branding, which is a condition for their placing on the EU market. The original directive from 2005 covered only energy-using products and was extended to energy-related products in 2009. The requirements on the individual product groups are set in implementing regulations. Regulation (EC) No 640/2009 implementing the Ecodesign Directive of 2005 sets minimum efficiency performance standards for EEMs in the following increments:

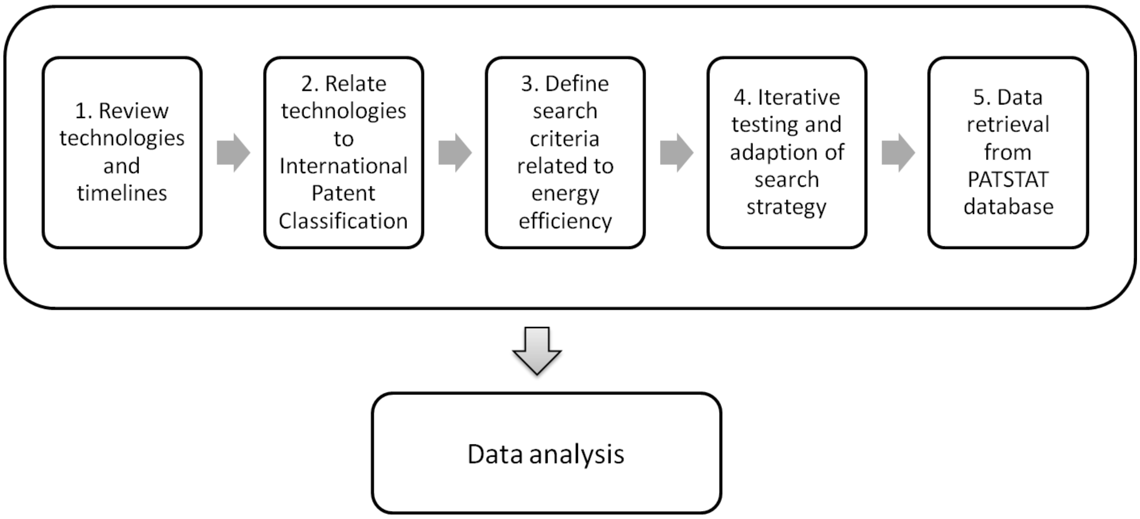
- From June 2011 on, motors must meet the IE2 efficiency level.
- From January 2015: motors with a rated output of 7.5 - 375 kW must meet IE3 efficiency level or the IE2 efficiency level and be equipped with a variable speed drive.
- From January 2017: all motors with a rated output of 0.75 - 375 kW must meet the IE3 efficiency level or the IE2 efficiency level in combination with a variable speed drive.

We investigate the effect of the regulation on innovation in EMDS technologies from two different perspectives: For the short-term diffusion, where the need for policy intervention is found to be mainly on the market formation side, the innovation impact of the policy measures is investigated through a multiple-case study research design. For the long-term development, where knowledge generation plays a major role, the innovation impact is studied by investigating the directives’ impact on the patenting activities of manufacturers EMDS. Beside the frequently discussed limitations of patents as innovation indicators, patents were identified as a suitable indicator for the function "knowledge generation" in the phase discovery.

4.2.1 Patent analysis

The impact of the policy measures on the research stage of the innovation process is studied based on patents related to energy efficiency for electric motors. The methodological approach for the patent analysis is illustrated in Figure 6.

Figure 6: Methodological approach for patent analysis



Source: own compilation

The study follows a five-step approach to collect data on patents relevant to energy efficiency:

1. Technologies: For each product, the technological details related to energy efficiency as well as emerging technologies are identified.
2. International Patent Classification: The IPC are identified[7].
3. Keyword search: Keywords to define properties related to energy efficiency are identified and tested.

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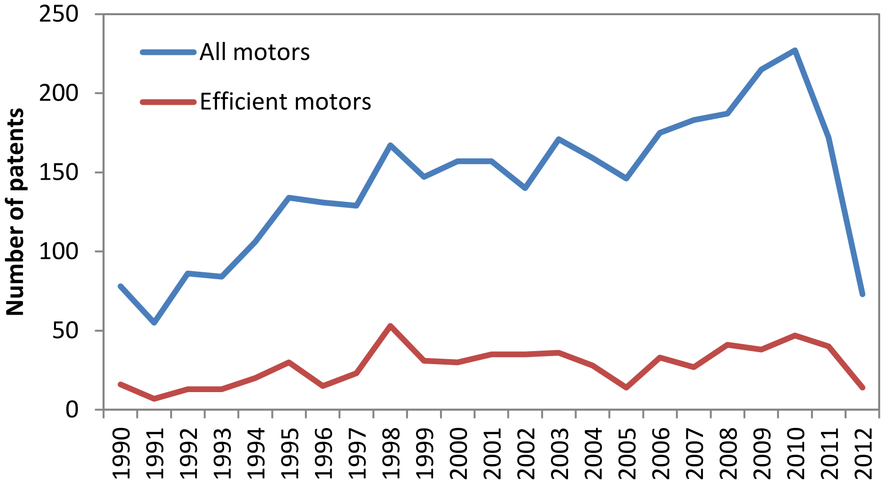
[7] More specifically, any patent needed to be in one of the following classes or subclasses thereof H02K 1/00, H02K 3/00, H02K 9/00, H02K 17/00, H02P as rather inefficient classes and H02K 15/03, H02K 21/00, H02K 1/17, H02K 1/27 as rather efficient classes. Additionally, to the patent class criterion above, title, abstract or claim text needed to contain the word “motor” or “machine”. For efficient asynchronous motors, any patent needed to be in one of the following classes or subclasses and contain the word “motor” or “machine” in the title, abstract or claim text H02K 15/03, H02K 21/00, H02K 1/17, H02K 1/27 as rather efficient classes or a patent could be in one of the following rather inefficient classes or H02K 1/00, H02K 3/00, H02K 9/00, H02K 17/00, H02P for the rather inefficient classes. For the inefficient patent classes, title, abstract or claim text needed to contain one of the following combinations of key words (“energy” OR “power”) AND (“save” OR “perform” OR “effi”) to count as efficient.

4. Testing: The search criteria are iteratively tested by analysing the percentage of false positives (patents that appear in the results but are not related to energy efficiency) and true negatives (patents that are related to energy efficiency but do not appear) until achieving a validity of at least 80% for both criteria
5. Data retrieval: The patent data is extracted from the PATSTAT database.

The influence of the policy measures on the patenting activities of manufacturers is investigated by comparing the evolution of patents related to energy efficiency prior to regulation, as well as after its adoption. *Trending behaviour* in patenting activities in these product groups are assessed relative to general patenting and economic trends. Sector specific developments driven by the directives are taken into account by studying the relative growth in the number of energy efficiency-related patents within the total number of patents for a given product. *Time lags* between research activities and the publication of a patent are considered to be slightly minor to the time difference between the announcement of a regulation and its adoption. We therefore assume that patents that were filed up to two years before the regulation (as well as patents filed thereafter) may have been regulation-driven, whereas this is not the case for patents filed prior to this time.

The data is shown in the following two figures (for European and worldwide patents separately). The count of patents per year for asynchronous motors generally grows in the EU during the observation period. The proportion of patents for efficient motors to all patents included, however, stays roughly the same (19%, standard deviation 5%). For 2012 and possibly less significantly also for 2011, many patents were not yet entered into Patstat.

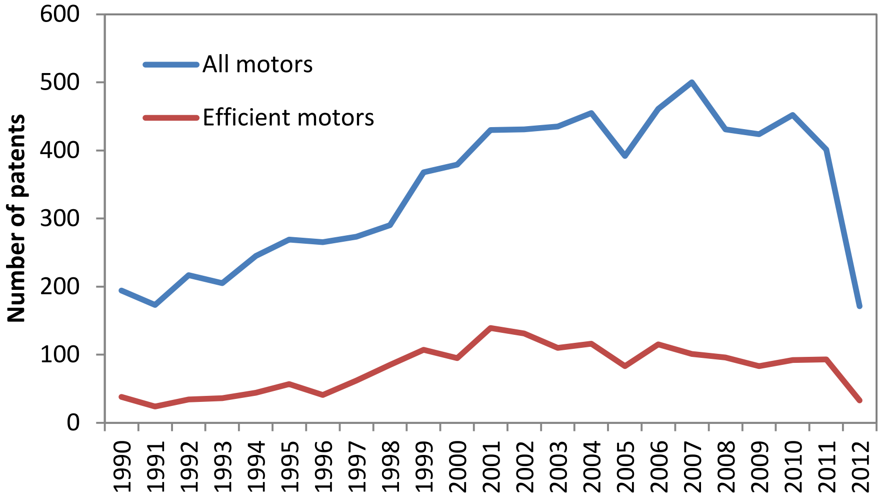
Figure 7: European patents for asynchronous motors



Source: own calculations based on Patstat database

Worldwide the count of patents per year for asynchronous motors doubles over the course of the 90s. Meanwhile the proportion of patents for efficient motors to all patents included only rises slightly (mean 19%, standard deviation 5%). Certain companies, most of all Japanese Minebea (with development and production also in other countries), seem to focus R&D on efficient motors. However, from the patent database it is not clear if their goal is to develop energy-efficient devices or if the technologies they use for most applications happen to be classified in this study as efficient.

Figure 8: Patents worldwide for asynchronous motors



Source: own calculations based on Patstat database

For each year the proportion of patents for efficient motors is considered denoted by EnEff. Thus EnEff is the ratio of the patent count for efficient motors to the patent count for all asynchronous motors. The following regression on the share of energy efficient-motors has been estimated by OLS:

$$\mathrm{EnEff}_t = \beta_0 + \beta_1 \,\mathrm{MEPS}_t + \beta_2 \,\mathrm{TREND}_t + \beta_3 \,\mathrm{EnEff}_{t-1}$$

Here, the following explanatory variables. MEPS is a dummy variable indicating whether a policy measure active, TREND is a trend variable using the natural logarithm of the actual year. We also included an autoregressive term in same regression models (e.g. from 2009 but also checked for other starting years between 2005 and 2010).

Table 6 summarises the different regression models used in our analysis.

Table 6: Variables for Energy efficient motor patents regression

Model no.	Patent data	MEPS = 1	Auto-regression $\mathbf{EnEff}_{t-1}$
1	EU-wide	2006	No
2	EU-wide	2006	Yes
3	EU-wide	2009	Yes
4	worldwide	2006	No
5	worldwide	2006	Yes
6	worldwide	2009	Yes

Source: own compilation

The policy instrument, represented by MEPS, is not statistically significant in all but one regression model. However, in regression model 4 where MEPS is significant with a strong negative influence, the influence of the prior-year is not being taken into account.

Table 7: Energy efficient motor patents regression results

European Patents	**Model 1: 2006**		**Model 2: 2006**		**Model 3: 2009**	
Variable	Est.	SE	Est.	SE	Est.	SE
MEPS	-0.0215	0.0386	-0.0181	0.0442	-0.0014	0.0384
TREND	0.0026	0.0028	0.0024	0.0033	0.0013	0.0023
Auto-regression	-	-	0.0449	0.2584	0.0925	0.2346

Worldwide Patents	**Model 4: 2006**		**Model 5: 2006**		**Model 6: 2009**	
Variable	Est.	SE	Est.	SE	Est.	SE
MEPS	-0.1016**	0.0319	-0.0537	0.0418	-0.0372	0.0336
TREND	0.0079**	0.0023	0.0040	0.0033	0.0020	0.0022
Auto-regression	-	-	0.4206	0.2506	0.5303*	0.2100

Significance levels: * 5% level, ** 1% level, *** 0.1% level

Source: own compilation

Overall no effect of the policy measure can be found in the proportion of patents for efficient asynchronous motors, worldwide or in the EU.

4.2.2 Case study approach

We studied the impact of the directives on process innovations and market formation using a multiple case study approach (Yin, 2002) to collect primary data. This approach allows for gaining in-depth insights into the causal links between the regulations and the innovation activities of the manufacturers. Our case study analysis is based on six semi structured interviews with experts from the electric motors and pumps sector. The interviews were conducted between August and December 2013 with representatives from 4 different companies as well as experts from non-governmental organizations and member state institutions. The company representatives included R&D management positions, product managers and leaders of the policy departments. The aim of our case selection was not to generate a statistical representative sample but include a broad range of companies taking into account the diversity and heterogeneity of firm-level innovation responses. To increase the validity of our results, whenever possible we included firms with similar characteristics as well as firms with contrasting characteristics in order to allow for literal and theoretical replication (Yin 2002).

All of the companies that were interviewed stated that legislation increases market opportunities for energy efficient products. Furthermore, all companies stated that the Ecodesign directive has an influence on their innovation behavior. The interviewees highlighted the importance of process innovations, e.g. the radical restructuring of production lines to allow for a cost-effective and large-scale production of (already existing) high-efficient technologies. However, its impact on more radical product innovations is limited as it rather serves to ban low-efficiency products from the market.

5 Conclusion and Outlook

We developed a conceptual approach for measuring the innovation impact of energy efficiency policies and have applied it to two case studies: Energy management systems and energy efficient electric motors. The two case studies highlight the importance of treating energy efficiency innovations at a systemic level, including a broad range of phases, actors and functions. Furthermore, the case studies highlight the important role of organizational innovations.

The suggested measurement framework mainly helps to organise the plethora of relations between actors and TIS functions in the different phases of the diffusion of innovations and allows a systematic analysis of policy effects in all these phases. Accordingly, it provides a framework to analyse existing findings and to identify research gaps. Furthermore, the structured approach disentangles the several dimensions in the development and diffusion of innovations for policy analysis. Although our measurement approach at first increases the complexity caused by the numerous possible combinations of phases, actors and functions, in turn it reduces the complexity by weighting the different combinations. Thus, uninteresting possible combinations will be eliminated and the problem will be broken down in fragments which allow a disaggregated analysis. However, availability of data which is required for the different combinations sometimes possibly only exists in a low quantity or quality.

The transferability of this approach to other (technological and non-technological) innovation systems should be investigated in detail. On the one hand the concrete application of the measurement approach depends on the characteristics and parameters of the innovation system analyzed. On the other hand not all reality aspects have to be described with the respective model or measurement approach in detail. One challenge still is to improve the availability of data for further empirical research.

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Appendix

The following table gives different examples for indicators for an application for wind energy, contracting, photovoltaic energy and energy efficient motors. Please note that this list is not exhaustive.

Table A1: Examples for indicators for an application for wind energy, contracting, photovoltaic energy and energy efficient motors

Field of application	Phase	Actor	Function	Relevant policy measures	Data	Indicator	Approach to measure policy influence	Reference examples
Wind energy	Discovery	Supply	Knowledge generation	Targets, R&D support, Feed-in-Tariffs	Patents by manufacturers, Research projects	Relative increase in wind patents with respect to total patents; Relative increase of research projects	Econometric analysis	Rogge et al. (2015); Pegels and Lütkenhorst (2014); Walz et al. (2008)
Wind energy	Discovery	Supply	Knowledge diffusion	Targets, R&D support, Feed-in-Tariffs	Data on investments (e.g. IEA database)	growth in private R&D funding and important R&D collaborations between manufactures and equipment suppliers	Econometric analysis	Quitzow (2015)

Field of application	Phase	Actor	Function	Relevant policy measures	Data	Indicator	Approach to measure policy influence	Reference examples
Wind energy	Take off	Supply	Entrepreneurial activities	Feed-in-Tariffs, R&D projects,	R&D projects, firm registries	Share of local (national) producers along value chain, entries in manufacturing and expansion of existing firms, increase in alliances with foreign companies	Econometric analysis	Bento und Fontes (2014) and references therein
Wind energy	Diffusion	Demand	Market formation	Feed-in-Tariffs	Installed capacity	Growth in installed capacity; total feed-in tariff+G7	Econometric analysis	Bento and Fontes (2014)
Wind energy	Diffusion	Demand	Legitimacy	Feed-in-Tariffs, structural policy measures	Data on project owners	Share of citizen-owned capacity	Case study interviews	Nolden (2013)
Contracting	Diffusion	Demand	knowledge diffusion	measure planned within NAPE[8]	-	Awareness of available programs promoting contracting	Cross-sectional analysis	-

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[8] NAPE = National Action Plan on Energy Efficiency (see also Federal Ministry for Economic Affairs and Energy, 2014)

Field of application	Phase	Actor	Function	Relevant policy measures	Data	Indicator	Approach to measure policy influence	Reference examples
Contracting	Diffusion	Demand	knowledge diffusion	measure planned within NAPE	not yet available	Awareness of contracting in companies	Cross-sectional analysis	-
Contracting	Diffusion	Demand	Market formation	Measure planned within NAPE	Not yet available	Achieved energy savings/energy cost savings	Cross-sectional analysis	-
Contracting	Diffusion	Demand	Legitimacy	Measure planned within NAPE	Seefeldt et al. (2013)	Perception of barriers regarding contracting	Cross-sectional analysis	Seefeldt et al. (2013)
Contracting	Diffusion	Supply	Market formation	Measure planned within NAPE	Seefeldt et al. (2013)	Number of new market entrants	Longitudinal analysis	Seefeldt et al. (2013)
Contracting	Diffusion	Supply	Market formation	Measure planned within NAPE	not yet available	Development of turnover share resulting from contracting projects	Longitudinal analysis	-
Contracting	Diffusion	Supply	Market formation	Measure planned within NAPE	-	Number of consultants	Longitudinal analysis	-

Field of application	Phase	Actor	Function	Relevant policy measures	Data	Indicator	Approach to measure policy influence	Reference examples
Contracting	Diffusion	Supply	Market formation	Measure planned within NAPE	-	Tapped potential	Longitudinal analysis	-
Contracting	Diffusion	Supply	Market formation	Measure planned within NAPE	Data set from study done by Prognos	Size and number of contractors	Longitudinal analysis	-
Photovoltaic	Discovery	Supply	Knowledge generation	EEG	Patent data	Patent counts, RPA, patent citations	Longitudinal analysis	Rogge et al. (2015)
Photovoltaic	Discovery	Supply	Knowledge generation	EEG	Survey data	R&D expenditures, number of employees in R&D	Longitudinal analysis	-
Photovoltaic	Discovery	Research system	Knowledge generation	EEG	EnArgus	Share of governmental funding in PV/ renewable energy	Longitudinal analysis	-
Photovoltaic	Discovery	Supply	Market formation	EEG	Project Gretchen	Number of new market entrants	Longitudinal analysis	-
Photovoltaic	Diffusion	Supply	Market formation	EEG	Project Gretchen	Turnover share with PV products	Country comparison	-
Photovoltaic	Diffusion	Supply	Market formation	EEG	Data from Photon Index	Specific costs for PV	Longitudinal analysis	Rogge et al. (2015)

Field of application	**Phase**	**Actor**	**Function**	**Relevant policy measures**	**Data**	**Indicator**	**Approach to measure policy influence**	**Reference examples**
Photovoltaic	Diffusion	Supply	Market formation	EEG	data from EPIA	Number of units sold, produced capacity	Longitudinal analysis	-
Energy efficient motors	Discovery	Supply	knowledge generation	Ecodesign	PATSTAT, Patbase, ESPACENET	Number/share of patents related to energy efficiency of electric motors	Longitudinal analysis	-
Energy efficient motors	Euphoria /disillusion ment	Research system	knowledge generation/ diffusion	Ecodesign	Publication databases (e.g. Scopus)	Number of publications regarding EEM	Longitudinal analysis	-
Energy efficient motors	Euphoria /disillusion ment	Policy	Influence on direction of search	Ecodesign, Labelling	-	National regulations, standards	Country comparison	-
Energy efficient motors	Euphoria /disillusion ment	Supply	Influence on direction of search	Ecodesign	EnArgus	Funding of relevant research projects	Longitudinal analysis	-
Energy efficient motors	Reorientation	Supply	Entrepreneurial experimentation	Ecodesign	Business notifications, national statistics	Insolvencies, new establishments of companies in relevant branches	Longitudinal analysis	-

Field of application	Phase	Actor	Function	Relevant policy measures	Data	Indicator	Approach to measure policy influence	Reference examples
Energy efficient motors	Reorientation	Supply	Entrepreneurial experimentation	Ecodesign, Labelling	R&D budgets	R&D budgets, R&D support	Longitudinal analysis	-
Energy efficient motors	Take off	Supply	Entrepreneurial experimentation	Ecodesign	Motorchallenge, EuroDEEM	Share of high efficiency class motor in product range of manufacturers	Longitudinal analysis	-
Energy efficient motors	Diffusion	Demand	market formation	Ecodesign, Labelling	CEMEP, ZVEI	Sales of efficiency classes IE1 to IE4 (by type: pumps, fans, etc)	Longitudinal analysis	Radgen et al. (2008); Falkner and Dollard (2008); de Almeida et al. (2008); Waide and Brunner (2011)
Energy efficient motors	Diffusion	Demand	legitimacy	Ecodesign, Labelling	CEMEP, ZVEI	Stocks of efficiency classes IE1 to IE4	Longitudinal analysis	
Energy efficient motors	Diffusion	Demand	legitimacy	Ecodesign, Labelling	Survey data	Ownership rates of EffCl IE1 to IE4	Longitudinal analysis	-