A comparative study on the consequence and impact of public policies in favor of solar photovoltaic (PV) development

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Abstract

This study aims at analyzing the impact of public policies intended to support photovoltaic (PV) development based on a comparative analysis of the largest installer (Germany) and the largest supplier (China) in the global PV market. A multi-perspective schematic diagram of the PV policies was therefore developed based on a concept of logic models to establish a common understanding of the PV policy mechanisms. This approach aims at providing an overview of the policies designed to support solar PV so as to understand the global mechanisms of PV strategies and their consequences; it includes key elements of policy objectives, inputs, output, outcomes and overall impacts. The conceptualized schematic model facilitates the cross-country comparison of policy strategies and results under different policy contexts and environments.

Introduction

Many countries set policy targets to support the development of new and renewable energy (NRE) technologies to address the major energy issues. Such policies set out to control greenhouse gas emissions while increasing the energy independency by diversifying energy sources to tackle the end of the cheap-oil era.

The practical application of solar photovoltaic (PV) started in the 1970s with the oil crisis (Green 2004) and has since become an ideal power source for decentralized electricity generation with the availability of abundant direct solar resources and its significant potential for climate change mitigation (Macintosh et al. 2011). Compared with other conventional energies, however, the decentralized intermittent PV energy source is not yet economically viable (Timilsina 2011) in many countries without policy support. The integration of PV in the current energy supply system is thus a challenging issue. Public support plays a major role to helping develop the PV energy system via various policy instruments. The PV development pathway highlights different aspects from one country to another country, which are influenced by different focuses on policy objectives or policy contexts. Some countries have concentrated on the energy transition via the development of new and renewable energies, combined with other economic goals. However, other countries have successfully created the PV industry without any serious promotion of domestic installations (de la Tour et al. 2010).

Comparing PV policy strategies to explain different PV development pathways helps improve our understanding of how desired or unexpected results are obtained with PV policy. However, it seems complex to carry out a cross-country comparison embracing multiple-perspectives due to the absence of commonly shared assessment methods across countries. Drawing a global overview of PV policy mechanisms is a practical tool for clarifying important influencing variables of PV policy systems. Visualizing the key elements of PV policy mechanisms in a single diagram is helpful in that it highlights the differences in the policy strategies and related results of the countries in question.

The objective of this paper is to recommend a standardized framework for comparative analysis, which helps demonstrate how different policy decisions bring about different results in support of solar PV energy systems. In order to build a common knowledge basis on which to evaluate the policy decision, the schematic PV policy system diagram is developed based on a concept of logic models. The theory of change is taken into account to help compare different pathways of the PV policy in Germany and China. This approach identifies important variables of PV policy mechanisms at a single glance within a global perspective. A comparative analysis is performed herein based on the developed schematic map so as to distinguish the characteristics and differences of policy decisions in Germany and China and to clarify interactions of their policy decisions with respect to PV policy mechanisms. Interactions between the German and Chinese policy are also reviewed taking into account their impact on the schematic map of the PV policy mechanisms.

Schematic diagram of photovoltaic (PV) policy mechanisms

The concept of logic models (also called the theory of change) is suitable for developing the schematic map to help visualize any key variables of PV policy systems in a single diagram and to explain how desired results are obtained via the graphical illustration of the policy mechanisms. The retrospective analysis using a common systematic tool facilitates comparative analysis by highlighting differences in policy strategies and consequences relative to the different PV development pathways. This approach clarifies the success and failure factors, and in doing so, comparative case studies can improve future policy actions to reduce risks or to respond to unexpected results.

Concept of logic models

Logic models provide a useful way to organize implicit information in mind and to display how an individual or group believes how their ideas should work. Such models employ a visual description of the sequence of planned actions and their expected results and changes in a single diagram (Knowlton & Phillips 2013). Logic models offer an illustrative description of elements belonging to a specific program or organization's change initiative (the theory of change) that outlines the relationship between the elements and desired outcomes (Conrad et al. 1999; Frechtling 2007). Graphical depictions are useful for demonstrating a systematic logical flow of intended transformations of resources, activities, outputs, and outcomes under certain situations (McCawley; Wholey 2004).

The basic components of logic models are:

1) Resources (human and financial resources, also referred to as inputs),
2) Activities (process, program, tools, events and actions) to bring about the desired results and changes,
3) Outputs (directed products, goods and services provided),
4) Outcomes (specific changes in behavior, skills, knowledge, and status or benefits from programs),
5) Impacts (fundamental, intended or unintended changes in organizations, communities, or systems) (Vedung 1997; The W. K. Kellogg Foundation 2004).

In addition, the model includes key contextual factors that have an important influence on the program; however, they are not under control.

Logic models have been used to assess policy programs over the past few decades to provide a strategic tool for critical thinking. Various refinements and changes of logic models have been made to the basic concept and many organizations now use these modified methods to address their needs (Wholey 2004). Logic models provide an efficient manner to illustrate the performance history or effectiveness of a specific program or organization's change initiative over time.

Schematic map of solar PV policy mechanisms

This study develops a simplified schematic map of solar PV policy mechanisms to understand the policy mechanisms at a glance based on the concept of logic models and the theory of change. The objective is to:

- Develop common understanding among stakeholders
- Identify important variables to measure the performance of PV policies
- Facilitate the cross-country comparison of solar PV policy based on a macro-perspective

In doing so, more importantly, the schematic model based on a macro approach can be used by policy makers to conduct regular policy assessments or to prepare new strategies and actions when facing unexpected results or change. This schematic map attempts to provide an overview of a country's PV policy roadmap from policy choice under certain policy contexts to the desired results and overall impact at the specific end. Accordingly, the map is used to explain the different pathways of PV development strategies and results in Germany and China, rather than focusing on clarifying one-to-one linear relations among elements.

The suggested schematic map has been developed taking into account existing practices of logic models and the theory of change, such as:

1) Theoretical background of a national R&D program evaluation (South Korea's Institute of S&T Evaluation and Planning 2005)
2) Evaluating EU activities: a practical guide for the Commission services (EU 2004)
3) DG MARKT Guide to Evaluating Legislation (European Commission 2008)
4) Historical Case Studies of Energy Technology Innovation (Wilson 2012).

The basic elements have been modified to adjust to the PV policy mechanisms. Figure 1 shows the model that includes **policy objectives, policy inputs (instruments), resources, outputs, outcomes, and contextual factors**; these elements are discussed in further detail below.

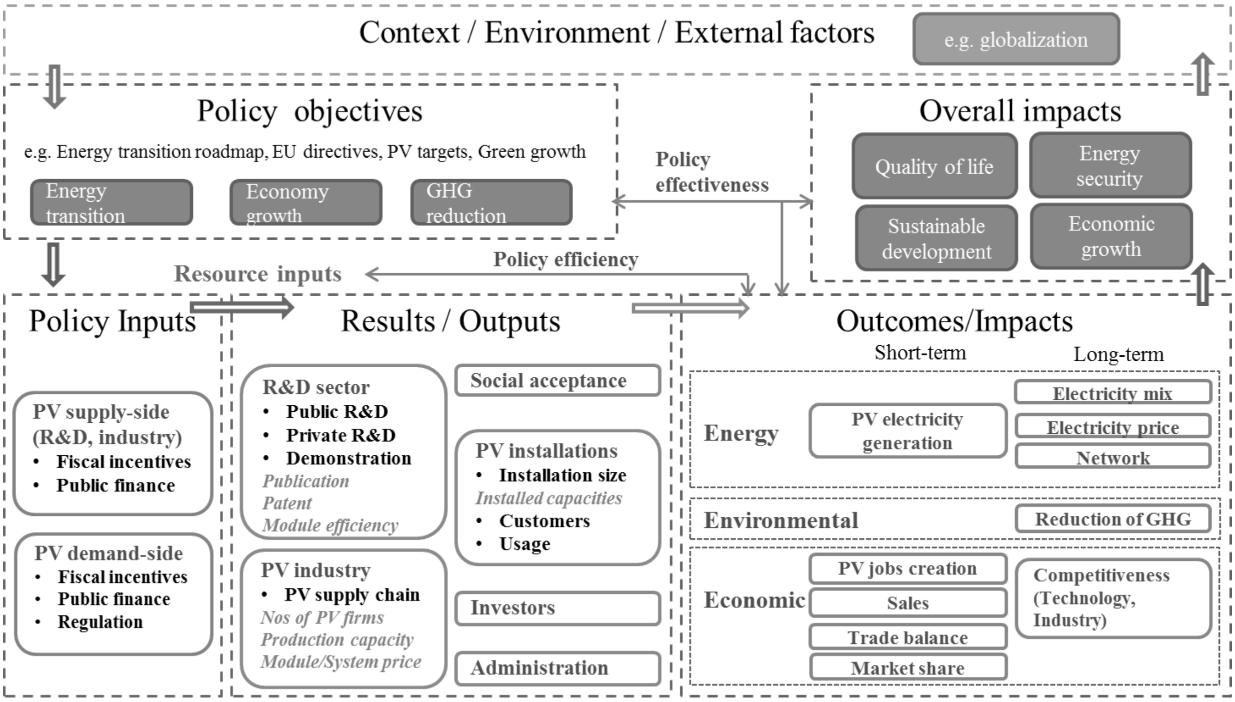

Figure 1: Schematic map of solar PV policy mechanisms

Policy objectives: There is a distinct difference in the decision-making process between the private sector and the government when it comes to investing in renewable energies; the former mainly invests in renewable energies to make profit, while the latter aims at improving social welfare. The government intervenes to resolve market failure and to ensure the internalization of externalities when the private sector invests below the socially optimal level. The balance between the market mechanisms and the government's role is important as these two elements complement each other; this balance will differ from time to time and from place to place (Stiglitz 2006). Finding the optimal balance in the energy sector is vital for the national development. The choice of public policy can be justified when the aim is to increase social benefits.

The policy objectives in PV policy mechanisms also differ from one region to another according to the national development and energy policy, as well as to the regional or national contexts. The decision maker's political opinion of the PV energy source also has significant weight when setting those policy objectives. How the PV energy system is supported depends on how a country perceives renewable energy sources in the energy mix. The general goal of policy in support of renewable energy sources is to achieve a sustainable energy system, which provides environmental, social and economic benefits to the society. This not only involves improving the cost-competitiveness of renewable technologies and sustainability in domestic energy production, but also the economic benefits such as its market share growth and job creation (IRENA 2012). Governments set policies to support renewable energies in order to address various objectives. The general objectives are to (Byrne et al. 2011; Macintosh et al. 2011, IPCC 2012);

- Enhance energy security via the diversification of energy supply technologies
- Mitigate global climate by the energy transition: reduction of greenhouse gas (GHG) emissions
- Improve access to energy, particularly in rural areas (energy equity)
- Seek social development and economic benefits, e.g. job creation and economic growth.

Differences in policy focus exist among countries; while energy security and environmental concerns are the main drivers in developed countries, socio-economic development and energy access tend to be the most important aspects in developing countries (IPCC 2007, 2012). In the early 1990s, only a few countries had rolled out policies to promote renewable energies. Since the early and mid-2000s, policy targets in renewable energies based on various policies have emerged in many countries (Mitchell 2012) to address concerns of sustainable energy systems and the environment, e.g. the EU's climate and energy objectives of 3x20 for 2020, which reflect its strong will to ensure its commitment to a low-carbon and energy-efficient society. By rolling out policy support with top-down policy objectives, the government plays a crucial role in advancing renewable energy technologies and in deploying them. In the schematic model application, the policy objectives of each country are defined in the schematic model application so as to provide the 'big picture' of the PV development pathway.

Policy inputs (actions, policy instruments): According to the policy objectives defined, policy inputs are determined with the allocation of resources. Policies in renewable energies are not confined to the R&D stage only. They also include efforts in commercialization and market development, from demonstration and pre-commercialization to large-scale production. However, there is no globally agreed list of renewable policy options; they can be defined in a variety of ways (Mitchell et al. 2012).

According to IPCC's special report, government support policies can be categorized into three groups; fiscal incentives, public financing, and regulations[1] (IPCC 2012). Based on existing literature (IPCC 2012; IRENA 2012) the schematic map in Figure 1 shows that the policy instruments supporting electricity generation via photovoltaic are reorganized into supply-side (R&D, industry development) and demand-side (installations) (Alloisio 2011; Finon 2008). Both policies influence the development of the PV manufacturing industry; the former directly aims at developing the PV manufacturing industry (technology-push) while the latter indirectly stimulates it to expand (demand-pull) (Alloisio 2011).

- Supply-side: technology-push policies to support R&D via technology and industry policies (e.g. subsidies for R&D, subsidies for industrial investment, fiscal incentives)
- Demand-side: market-pull policies to provide incentive for the diffusion of solar PV energy such as subsidies and incentives for electricity production (e.g. FIT) or PV system installation

Through the mix of policy instruments, government programs aim at achieving above-policy objectives. The clarification of policy input is useful for reviewing the focus area of country PV policy strategies. In the comparative analysis using the map, policy strategies and inputs are reviewed according to **R&D, industry and installations aspects** with generated results.

Outputs: Outputs are generated direct results (products and services) in terms R&D, industry, installations, and other important results (administrations, social acceptance, applications and investor choices). They can be determined using measurable variables; for example, patent application and publications for R&D policy effects (Popp 2010; Prodan 2005; Wilson 2012), changes in the manufacturing production capacity for industry growth, and increases in installed capacity for national installations.

In the study below, variables are reviewed to conduct a comparative analysis of Germany and China**.**

- **R&D sector: patent, publication, and module efficiency**
- **Industry: number of firms, production capacity, and module/system prices**
- **PV installation: installed capacity**

Outcomes (impact): Outcomes are the direct and indirect results including changes and benefits in the short-term and long-term perspectives; this study takes into account the energy, economic and environmental aspects. To give an example, reduced GHGs can be used to measure the environment benefits, while job creation and trade balance can be considered to review economic benefits. In addition, the energy transition's impact is determined by comparing changes within the PV electricity generation in the electricity mix (Macintosh et al. 2011). Energy equity is a longer-term impact

1 **Fiscal incentives**: reduction of a player's contribution to the public treasury through tax deductions (such as income tax or other taxes), rebates, grants, **Public financing**: public support such as loans, equity, or financial reliability such as guarantees, and **Regulations**: rules to guide or control (IPCC 2012)

indicator related to energy access or electricity prices. It is also important to include network improvements to address the issues of intermittency. The competitiveness of the industry can be determined by reviewing changes in the global market share. In this study, measurable variables are considered in order to review PV policy results in German and China.

- **Energy transition: PV electricity generated and percentage in the energy mix**
- **Environment benefits: GHG emissions avoided**
- **Economic benefits: jobs, trade balance, sales, and market share**

Overall impact: These defined outcomes ultimately aim at improving the overall effects on society relative to the **quality of life, energy security, sustainable development (**IPCC 2007, 2012) **and economic growth** (Solangi et al. 2011) through the development of solar PV energy systems. In the comparative analysis, the overall impact associated with the country's policy objectives is reviewed to clarify differences in the social benefits generated in both countries.

Key contextual factors: This part includes various contexts, environments, natural resources, and external factors that influence the PV policy mechanisms. They are not, however, under control. The influencing factors hold different aspects in regional, national and energy contexts. There are various factors affecting the mechanisms, e.g. energy price, human resources such as the price of labor (Grau et al. 2011) or education, electricity network quality (IEA PVPS), scarcity of domestic energy supply (Alloisio 2011), and the social opinion on energy sources (Lauber et al. 2004). The key contextual factors change over time and are influenced by various aspects. In this study, the globalization as an influencing external factor is reviewed as a consequence of German and Chinese interactions.

Evaluations: It is important to define the desired results in comparison with policy objectives for the entire evaluation process. There are some criteria to assess energy policies that can be found in most literature; they are effectiveness, efficiency, equity, institutional feasibility (Mitchell et al. 2012), replicability (IRENA 2012), consistency and coherence (Bohm et al. 1985; IPCC 2012). Among them, effectiveness and efficiency are the most commonly used standards to determine the success of policy instruments (Mitchell et al. 2011); **effectiveness**: to what extent is the intended objective met? (policy objectives vs. outcomes), **efficiency**: what is the ratio of outcomes to inputs? (policy inputs vs. outcomes). This study attempts to review the effectiveness of PV policies so as to assess which desired results are obtained compared with the policy objectives.

Case studies applying the schematic map of solar PV policy mechanisms

Comparative analysis of the solar PV policies between Germany and China

The schematic evaluation map is useful for demonstrating the different pathways of the two countries' strategies designed to support PV and their related results. However, solar PV policy mechanisms are complex and integrate various variables in multi-perspectives. It is thus not always possible to clarify linear causal relationships among inputs, outputs and outcomes.

The comparative analysis is based on the proposed schematic map of PV policy mechanisms; Germany and China were selected for the comparative analysis because they are the leaders in global PV demand and supply respectively. Using previously-identified variables, the comparative analysis attempts to identify policy objectives and key strategies to understand generated results and overall impacts, somewhat aggregately observed over time. The analysis also reviews how the PV policies interacted between both countries and thus provoked changes in the key contextual factors and impacted the schematic map.

PV policy objectives in Germany and China

Solar PV development in Germany and China started under very different policy objectives.

Faced with the oil crisis in the 1970s, Germany began to promote renewable energy sources with the solar PV energy system being one of the sustainable energy sources promoted to increase the national energy security. Later, the Chernobyl nuclear accident provoked social pressure to shift towards more sustainable energy sources. In addition, the EU's GHG emission reduction targets drove Germany to engage in more sustainable energy systems. The German PV policy objectives aimed at developing a sustainable substitute of conventional energy sources and at mitigating the global climate change (Lauber 2004). The Renewable Energy Sources Act (EEG), which was published in 2000, supports these national energy transition goals. Under the EEG, the German government decided to stimulate the increase in demand by including PV energy systems. Germany also intends to boost the PV industry to generate more economic benefits (e.g. economic growth, job creation) (Alloisio 2011).

China's energy policy mainly aims at securing a stable energy supply to balance its growing energy needs. China's PV development started with the supply of electricity to off-grid rural areas. Under the 10th (2001-2005) and 11th (2006-2010) 5-year plans in China, the government strove to control air pollution by SO2 and CO2 (by-products resulting from the excessive use of conventional energy sources, mainly coal). In 2006, under the 11th 5-year plan, PV was selected as a technology to improve national knowledge on energy technologies. However, the municipal government first aimed at developing the PV industry to promote high-tech manufacturing in pursuit of economic benefits (Deutch et al. 2013) under the regional industrial policy to boost economic benefits. Under the 12th 5-year plan (2011-2015), the solar PV industry was included in the list of national initiatives to further expand the new energy industry by developing clean energy technologies and related industries (British Chamber of Commerce in China 2011). The government also aimed at developing the domestic market through the expansion of large-scale power plants (Lewis 2011).

Policy inputs and results

In line with the policy objectives described above, the policy inputs were then decided together with resource allocation in both countries. It is interesting to review their different approaches to developing the solar PV sector. Policy support (strategies and inputs) in both countries and the related results are given below according to R&D, industry and installation aspects. This is done to simplify our explanation by using identified key variables.

R&D: policy strategies and inputs

Over the last decades, solar PV energy solutions have experienced visible technological progress (Timilsina 2011) thanks to the continuous R&D activities in developed countries. Knowledge acquired from research is transferred to firms, other research institutes and overseas countries through publications, patents and other forms of scientific communication (Mamuneas 1996).

As a pioneering country, German R&D development in PV almost followed the classic linear model of innovation from early R&D investment, followed by demonstration and commercialization (Lauber et al. 2004; Mints 2011). Since the early 1980s, Germany has put a great deal of effort into the PV sector, whether this be in R&D, demonstration or investment led by advanced research centers, universities and combined industrial companies of PV components. This has created a close network in the PV sector. Since Germany's disengagement from nuclear power in the early 2000s, part of the nuclear R&D budget was transferred to the renewable energy sectors (Lauber et al. 2004). With the inflow of cheap Chinese products since the late 2000s, German R&D started to focus on further reducing the production costs of silicon-based technologies to support the German industry. At the same time, the country strengthened its skills in PV components and equipment (Grau et al. 2011).

However, even though China took up research work to develop solar PV in the late 1950s and entered the application stage in the 1970s, the Chinese government efforts in PV R&D were negligible until recently. It mainly aimed at increasing the production of cells and modules with focus on easy-to-follow technologies rather than serious R&D (de la Tour et al. 2010). As indicated in **Table 1**, there is a significant difference between Germany and China in terms of resource-allocation decisions for R&D expenditures in PV.

	2001-2005	2006-2010	2012
Germany	US$ 138 M	US$ 388 M	US$ 66 M
China	US$ 5.2-6.2 M	US$ 25.6 M	US$ 79 M

Table 1: Public budgets of PV R&D in Germany and China (IEA PVPS)

R&D: generated results (outputs and outcomes)

The silicon **module efficiency** improved to over 20% in 2012 thanks to continuous R&D (Knoll et al. 2013). The domestic R&D results are reviewed with changes in **patents** in both countries. Germany and China have visible differences in the contribution to the world patents in the solar PV sector. Along with their continuous efforts in R&D activities, Germany was responsible for a significant proportion of the global patents.

Nonetheless, China recently started to focus more on R&D to advance PV-related technologies such as silicon production to catch up with the major producing countries (de la Tour et al. 2010; IEA PVPS). Therefore, China has only recently gained visibility in terms of producing international patents. Under its 12th plan, China included the PV sector in the list of government-driven R&D initiatives; e.g. Si-cell efficiency of 20% and thin film cell efficiency above 10% and reducing production costs (IEA PVPS).

Patents: cell & modules	1995	2000	2004	2007	2010	2013	**Patents**: silicon refining	1995	2000	2004	2007	2010	2013
China	0.3	0.4	0.9	2.0	4.1	2.7	**China**	0.8	0.6	0.4	2.5	7.1	5.4
Germany	6.4	7.3	7.7	7.8	7.7	6.3	**Germany**	17.0	13.9	13.4	11.2	8.4	7.0

Table 2: Patents for cells & modules and patents for silicon refining; Unit: cumulative % of the global patents (Espacenet)

PV industry development: policy strategies and inputs

Solar PV industry development is a result of technology-push and/or demand-pull strategies. The industry development can have a different policy mix between the deployment of renewable energies, the expansion of manufacturing capacities, and the access to export markets (IRENA 2011). Comparison of PV industry policy strategies in Germany and China here below is demonstrated by focusing on the characteristics of policy inputs to promote the PV industry.

Germany decided to invest in the PV industry for both environmental and economic reasons. The German PV market developed thanks to synergies resulting from the success of technology-push and market-pull policies (Alloisio 2011). Germany supported the PV industry with generous funding mainly from the German federal government, the EU and the individual federate states (Grau et al. 2011; IEA PVPS). Various supporting instruments were also put in place to develop the German PV industry; e.g. grants or cash incentives for direct investment before operation, reduced-interest loans by the national development bank & state development banks, and public guarantees to secure bank loans.

China, however, adopted a different industry policy strategy. The nation’s industrial policies were export-oriented, beginning with labor-intensive downstream manufacturing (modules and cells) before the mid-2000s because of accessibility to technology and low energy prices. China’s PV industry has grown explosively since the mid-2000s, supported by government aids for innovative industry, particularly in crystalline silicon solar cells production (Zhang 2013). From 2006, China started focusing on PV material production and entered into higher-skilled, more capital-intensive upstream industry (silicon purifying, ingots shaping and making thin wafers). The Chinese government prepared policy supports based on investment in PV manufacturing through innovation funds for small technology-based firms, regional investment support policies[2] issued by some Chinese city governments, and simplified loan and credit conditions provided by government/state banks for manufacturers.

PV industry development: generated results (outputs and outcomes)

In this section, the results of the PV industry for both countries are reviewed with respect to changes in the **manufacturing capacity** and the **module production cost.** Economic benefits are seen via **jobs, sales and trade**. In addition, the competitiveness of the PV industry is considered together with the **market share**.

The German cell **manufacturing capacity** increased 51 times from 57 MW in 2000 to a peak of 2,919 MW in 2011, before it was halved in 2012 due to the PV crisis (IEA PVPS). The **module price** reduced from $6.8/Wp 1992 to $2.9/Wp in 2008, which further reduced to $0.69/Wp in 2012 with the emergence of Chinese products boosted by large-scale production (IEA PVPS 2013). The **system price** also decreased from $8/Wp in 2000 to less than $3/Wp in 2012 for rooftop systems under 10 kW. Even though Germany successfully accomplished the industrialization of PV over the last

2 E.g. Refunds of loan interest, of electricity consumption fees, land transfer fee, corporate income tax, and of value added tax payment

decades, the domestic production capacity did not fulfill the country's domestic demand for installations, and Germany imported PV products to some extent (BMU 2009). Furthermore, the German PV industry created **economic benefits**; 128 thousand direct **jobs** in 2011 with **sales** valued at US$ 21 billion and **exports** to US$ 7.3 billion in 2011 (IEA PVPS; UNCOMTRADE). However, with the emergence of the Chinese competitive products since 2008, Germany's industry **market share**[3] in PV cell production reduced in the global PV market from 22% in 2007 to 2% in 2013. In addition, faced with the European PV crisis and fierce global competition, the German PV industry fell hard; around 30,000 **jobs** were lost in 2012 and **export** decreased by 40% (IEA PVPS; UNCOMTRADE). The German industry strategically put more focus on high-skilled sectors such as refining silicon and equipment production (Grau et al. 2011).

China took the leading position in solar PV manufacturing industry in a short period (Xie 2012). Since mid-2000, China has exported the majority of its module production (97.5% in 2007). China's cell **manufacturing capacity** increased rapidly from 400 MWp in 2006 to 26,015 MWp in 2013, i.e. 63% of the global production. The **module production price** rapidly reduced from $4.7/Wp in 2007 to $0.7/Wp in 2012 (IEA PVPS 2013). Through the industry development, China created 500,000 PV **jobs** in 2011 and 300,000 in 2012 (IEA PVPS). PV materials **exports** totalled US$ 17.5 billion in 2012 (UNCOMTRADE). In addition, major PV manufacturers were now headquartered in China. The fraction of the PV industry in the Chinese economy grew; PV **sales** accounted for 0.6% of the Chinese GDP, representing US$ 48 billion in 2011(IEA PVPS). China's **market share** in the global PV cell production rapidly increased in a short time, from 16% in 2006 to over 50% in 2011 (IEA PVPS). However, China imported a large portion of its silicon materials for massive-scale production due to the existing technological barriers. China's PV sales are heavily dependent on the overseas market due to the lack of a domestic market. In 2013, China's cell **manufacturing capacity** increased to 26,015 MW (60% of the global production).

PV installations: policy strategies and inputs

A policy that supports demand helps to promote national PV installations by inciting commitments from more stakeholders. Germany and China have different PV installation characteristics owing to the different national strategies vis-à-vis the energy transition and the mitigation of climate change.

German has a long history in PV installation; the first PV target subsidy scheme started with '1000 Solar Roofs Initiative' (1991-1995) (Byrne 2011). The '100,000 Solar Roofs Initiatives' (1999-2003) was then rolled out, causing a rapid increase in PV system installations in the early 2000s (Lauber 2004). Finally, under the EEG which was designed to ensure Germany's energy transition, the FIT scheme was rolled out in 2000 (Grau et al. 2011). It played an important role in the German solar PV boom from 2004 (Yang 2010).

FIT (M€, 20 years)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Germany	559	442	563	897	1913	6027	7164	8969	8409	9032	9296

Table 3: The German FIT cumulative costs (IEA PVPS; Lütkenhorst et al. 2014)

Table 3 highlights the constant commitment of the German government and the continuous growth in Germany's installed capacity since 2000. Germany invested €53 billion (cumulated for the 20-year contract) in direct support for PV deployment through the FIT system until 2010 (Lütkenhorst et al. 2014).

China's Solar PV power generation started in the 1960s but its dramatic progress is a recent event in the last 10 years (Zhao et al. 2013). The first political support to promote solar PV deployment was implemented through off-grid rural electrification programs; the Brightness Program (1996) and the Township Electrification Program (2000). Until the mid-2000s, however, China's solar PV sector was still in its infant stage with less than 100 MW of cumulative solar electric power (IEA PVPS 2013). The serious rollout of policy instruments for PV deployment promotion started from the mid-2000s with the renewable energy law (REL) in 2006 (Xie 2012). Faced with a sharp rise in demand for energy consumption caused by the rapid economic development, China began to include sustainable development in its energy plan. In 2007, China announced its medium- and long-term program of

3 Authors' calculation based on IEA PVPS data

renewable energy development with energy supply targets using renewable energy technologies; the PV installation targets are 5 GW by 2015 and 20 GW by 2020 (Grau et al. 2011). Chinese national PV installations reached a serious level in 2009 thanks to the national strategy for domestic market growth. Grid-connected rooftop and building-integrated PV (BIPV) installations rose sharply thanks to incentive programs which started in the late 2000s; central government subsidy programs were launched such as the Rooftop Subsidy Program (2009), the Golden Sun Demonstration Program (2009), and the Solar PV Concession Program (2009). Furthermore, China recently needed a new market to absorb its excessive production due to the diminishing demands in the European market. In 2011, the national FIT scheme was set to support domestic growth.

PV installations: generated results (outputs and outcomes)

In this study, policy strategies are reviewed through direct changes in the **installed capacity**, the impact on the energy transition (**electricity generated using PV, electricity mix**) and the environmental impact (**GHGs avoided**).

Germany became the world largest PV market thanks to the government's constant affirmation through support policies. This resulted in a **cumulative installation** of 32.5 GW in 2012, accounting for 26% of the global installation. The **business value** of the German PV installation market was valued at $17,520 million in 2012. Supported by the EEG, the German energy transition proved successful by turning renewable energies from a niche market into a visible energy source (Gabriel 2014). The solar PV contribution to the annual **electricity production** increased to more than 5% producing 28 TWh from its initial 0.03% with 0.2 TWh in 2002 (EPIA 2013; Eurobserv'er 2013a). These resulted helped to avoid producing about 10 million metric tons of **CO2 emissions** (Fraunhofer 2012).

Installations (MW)	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Germany	76	296	435	1105	2056	2899	4170	6120	9914	17320	24820	32420	35500
China	19	42	52	62	70	80	100	140	300	800	3300	7000	18300

Table 4: Cumulative installed capacities of PV in Germany & China (IEA PVPS; Lütkenhorst et al. 2014)

China contributed significantly to the global PV capacity, representing 12% of the new installation capacity in 2012 (IEA PVPS). China reached 7 GW of PV **cumulative installed capacities** in 2012, which accounted for around 7% of the global total output (IEA PVPS; EPIA 2013). This nonetheless represents a negligible contribution to the **electricity generation**, amounting to 0.1% in 2012 and producing 5.2 TWh (Eurobserv'er 2013b). Accordingly, its impact on reducing **CO2 emissions** is poor; rather it increases steadily every year from 4.1 in 2004 to 6.2 metric tons per capita in 2010 (The World Bank). The **business value** of the Chinese PV installation market was estimated at $6,143 million in 2012.

Overall impact of PV policies in Germany and China

Germany and China followed very different policy pathways to support PV development.

German PV development started with focus placed on its energy transition towards a sustainable energy supply system; however, technology development through continuous R&D activities and industry growth are also important objectives. The well-balanced policy mix around supply and demand put the country in the leading position and was producing visible results with respect to the energy transition and economic benefits until recently. However, the situation changed as the competition started with the emergence of Chinese large-scale production lines in the late 2000s. The German PV industry was influenced by the inflow of cheap Chinese products, thus provoking economic damage (job loss, trade deficits). The current German PV sector is experiencing a slowdown and PV growth driven by crystalline silicon technology is shifting to other regions. Furthermore, PV electricity overproduction due to good weather also raised the issue of a negative electricity gross price for the European electricity market (RTE 2013).

The Chinese policy started concentrating more on its industry development through export-driven strategies to increase its international competitiveness, rather than ensuring the energy transition. The PV sector obtained visible economic results, producing more than 70% of the PV cells for global needs in 2012, though with very tenuous outcomes in terms of the energy transition and climate change. Furthermore, China still has a weakness when it comes to raw materials and equipment for the PV industry as it greatly depends on overseas production. Unlike the German pathway, China's new energy plan aims at stimulating domestic demand through sustainable energy supply systems, which seems to be a timely solution to respond the PV industry slowdown.

Interactions between Germany & China PV policy strategies: impact on the schematic map

The combined case study of Germany and China has allowed us to perceive the importance of external factors in the schematic map proposed. The external factor in this case is **globalization**. The PV policy mechanisms can be described as a dynamic system that evolves over time. The Chinese PV policy mainly aimed for economic benefits without developing its local market. This influenced the implementation of the German policy to some extent because it generated new conditions that contradicted the assumptions on which the German policy was based.

When the Chinese producers sharply reduced their module prices based on economies of scale with large-scale production lines from 2008, the German module prices had to fall into line with those of the Chinese products due to PV globalization (see **Table 5**). In 2009, the German PV system prices fell much faster than expected under the policy design, provoking uncontrolled PV installations and additional policy costs. The German FIT scheme was designed on the assumption that there was little global competition and any domestic increase in demand would be largely supplied by the German production. But this was before the Chinese appeared. The German policy was set by extrapolating the drop in module prices according to observed R&D effects.

$/Wp	1992	1997	2002	2004	2006	2007	2008	2009	2010	2011	2012
Germany	6.8	4.7	2.9	3.7	5.0	4.1	2.9	2.1	2.6	0.8	0.7
China						4.7	4.3	2.8	1.9	1.4	0.7

Table 5: **Modules price** changes in Germany & China (IEA PVPS)

German installers began to use price-competitive Chinese products to increase their own profit margins, which led Germany to curtail the FIT scheme several times to adjust to such market changes. However, the adjustment was not enough to respond the market change. Germany recorded a €3.5 billion **trade deficit** in solar components with China during 2010 to 2012 (European Commission 2014). The reduced financial incentives in the European market caused by the global economic crisis shrank the global demand (IRENA 2013), thereby provoking economic damage on both the German and Chinese side. For example, through the restructuring plans after the global PV crisis, **the number of companies** in PV manufacturing (silicon refining through to module assembly) fell to 150 in 2013 from around 750 in 2010 (Sheppard 2013). China's continuous massive production without suitable outlets for their production destabilized the global supply-demand PV system.

From here, the schematic map of solar PV mechanisms provides a constant framework which can be used to prepare future actions under such variable changes. Policy makers need a macro-view of policy mechanisms to react to the unexpected results, as well as to deliver future strategies which do not repeat the same situation. This case study allows German policy makers to understand the importance of external influencing factors so they can seek benefits in the globalized market while taking such factors into account. In addition, China needs a well-balanced policy mix to achieve long-term benefits; otherwise, their industry-focused policy strategy, which heavily depends on the overseas market, is too risky to pursue.

Conclusion

A better understanding of the differences between policy strategies and results will provide opportunities for benchmarking so as to improve future policy design (Knowlton & Phillips 2013). In most countries, governments usually search for energy supply and security, sustainability, and adaptation or mitigation to climate change for energy policies. Economic benefits such as job creation or export are also important levers for government energy policies (White 2013). As seen in this paper, the energy policy pathway will vary from one country to another because of different policy strategies and influencing factors. Case studies of the German and Chinese pathways for PV development clearly demonstrated the different policy strategies together with very different results and benefits.

PV policy design and implementation should not be restricted to choosing between technology-push policies and demand-pull policies. A multi-perspective approach is a valuable tool for reviewing PV energy policies and the consequences associated with the influencing context and environment from a global perspective. An optimal mix of policy instruments is important for the success of any PV policy; however, the cogitation of external factors and their possible interactions (e.g. globalization) are equally important if we wish to achieve the desired benefits.

PV policy mechanisms have complex interacting systems. The accuracy of the proposed schematic map can therefore be improved with more knowledge and experience which can only be done by taking into account stakeholders practices and contributions. The findings in this study can be integrated into the schematic map. For example, as Germany is aware of the impact of an open market, the future policy design needs to take them into account; e.g. institutional barriers such as certification or agreements with building companies for PV integration like the Japanese systems, or by looking to create new demands with new technologies and usages. In addition, China needs to fully understand the importance of well-balanced policies for long-term benefits; the energy transition towards a sustainable energy system can open new industry opportunities in China.

Furthermore, this approach aims at highlighting the importance of regular policy assessment to increase the accuracy of policy implementation. Only in this way can the desired goals be achieved, considering that policy contexts and environmental aspects change over time since they influenced by various movements. Such conditions tend to be in contradiction with the very assumptions used to define policy. A systematic approach to monitoring any pathway changes based on this schematic tool can be used to clearly explain the mechanisms involved before taking the steps to prepare new policy strategies which reflect the new conditions.

References

Alloisio, I. 2011. The Policy Drivers of PV Industry Growth. Paper presented at the 26th European Photovoltaic Solar Energy Conference and Exhibition

BMU, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2009. *Report on the Environmental Economy 2009, Fact & Figures for Germany*

Bohm, P., C. S. Russell. 1985. “Comparative Analysis of Alternative Policy Instruments” In *Handbook of Natural Resource and Energy Economics* 1, A.V. Kneese and J.L. Sweeney (eds.).

British Chamber of Commerce in China. 2011 . *China’s 12th 5 Year Plan (2011-2015): The Full English Version*

Byrne, J., L. Kurdgelashvili. 2011. “The Role of Policy in PV Industry Growth: Past, Present and Future” In *Handbook of Photovoltaic Science and Engineering* (Second Edition), John Wiley & Sons, Ltd

Conrad, K. J., L. R. Frances, M. W. Kirby Jr., R. R. Bebout 1999. “Creating and Using Logic Models: Four Perspectives.” Co-published simultaneously in *Alcoholism Treatment Quarterly* The Haworth Press, Inc. Vol. 17, No. 1/2, 1999, 17-31 and *Homelessness Prevention In Treatment of Substance Abuse and Mental Illness: Logic Models and Implementation of Eight American Projects* The Haworth Press, Inc. 17-31

De la Tour, A., M. Glachant, Y. Ménière. 2010. “Innovation and international technology transfer: The case of the Chinese photovoltaic industry” In *CERNA Working paper series* 2010-12

Deutch, J., E. Steinfeld 2013. *A duel in the sun: The solar photovoltaics technology conflict between China and the United States* MIT

Espacenet. http://worldwide.espacenet.com (silicon refining: PV, solar, photovoltaic with IPC=C01B33; cell and module: solar cell, PV, solar, photovoltaic with IPC=H01L)

Eurobserv’er 2013a. *Worldwide electricity production from renewable energy sources, Stats and figures series*. *Survey of regional dynamics by sector*. Fifteenth inventory

Eurobserv’er 2013b. *Renewable origin electricity production: detail by region and country*. Chapter 3.12.1: China. Fifteenth inventory

European Commission 2014. *Energy Economic Developments in Europe*

European Commission 2004. *Evaluating EU Activities: A Practical Guide for the Commission Services*

European Commission 2008. *DG MARKT Guide to Evaluation Legislation*

European Photovoltaic Industry Association (EPIA) 2013. *Global market outlook for photovoltaics 2013-2017*

Frechtling, J. A. 2007. *Logic modeling methods in program evaluation*. John Wiley and Sons

Finon, D. 2008. “L’inadéquation du mode de subvention du photovoltaïque à sa maturité technologique” In *CIRED & Gis LARSEN Working Paper*, December

Gabriel, S. 2014. “Germany’s energy transition: a strategy for mitigating climate change and boosting growth” In *The European Files* 32 march-April, European Commission

Grau, T., M. Huo, K. Neuhoff. 2011. “Survey of Photovoltaic Industry and Policy in Germany and China” *Energy Policy* 51 (2012) 20-37

Green, M. A. 2004. “Recent developments in photovoltaics” *Solar Energy* 76 3–8

IEA. China : Global Renewable Energy: Solar Power Technology Development 12th Five-Year Special Plan
IEA PVPS. *National survey report of PV power applications in China* 2011& 2012, *in Germany* 2002 to 2011
IEA PVPS. *Trends in photovoltaic applications* 2002 to 2013, *Annual report 2013*
Intergovernmental Panel on Climate Change (IPCC), Working Group III: Mitigation of Climate Change, 2007. *Climate Change 2007* Chapter 4: Energy Supply
Intergovernmental Panel on Climate Change (IPCC) 2012. *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change* 871-872 Cambridge University Press
IRENA 2011. *Renewable Energy Jobs: Status, Prospects & Policies. Biofuel and Grid Connected Electricity Generation.* Working Paper
IRENA 2012. *Evaluating Policies in support of the deployment of renewable power*
IRENA 2013. *Solar photovoltaics technology brief*. IEA-ETSAP and IRENA© Technology Brief E11 January
Korea Institute of S&T Evaluation and Planning 2005. *Theoretical Background of National R&D Program Evaluation*
Know, B., J. Siemer 2013. *Still more than enough*. Photon International February 2013 p 73.
Knowlton, L. W., C. C. Phillips. 2013. “The Logic Model Guidebook: Better Strategies for Great Results” Second Edition. Chapter 1: Introducing logic models. SAGE Publications, Inc
Lauber, V., L. Mez. 2004. “Three decades of renewable electricity policies in Germany” *Energy & Environment* 15 (4) 599-623
Lewis, J. 2011. “Energy and Climate Goals of China's 12th Five-Year Plan” for the Center for Climate and Energy Solutions (C2ES)
Lütkenhorst, W., A. Pegels. 2014. Germany’s Green Industrial Policy Stable Policies, Turbulent Markets: The costs and benefits of promoting solar PV and wind energy prepared for The International Institute for Sustainable Development, Research report January
Mamuneas, T., M. I. Nadiri 1996. “Public R&D policies and cost behavior of the US manufacturing industries” *Jounal of public economics* 63 57-81
Mac Cawley. The logic model for program planning and evaluation. University of Idaho www.d.umn.edu/~kgilbert/educ5165-731/Readings/The%20Logic%20Model.pdf
Macintosh, A., D. Wilkinson 2011. “Searching for public benefits in solar subsidies” *Energy Policy* 39 Issue 6 3199–3209
Mints, 2011. The history and future of incentives and the photovoltaic industry and how demand is driven. Paper presented at 26th EU PVSEC
Mitchell, C. et al. 2011. *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change* Chapter 11: Policy, Financing and Implementation 865-950 Cambridge University Press
Popp, D., I. Hascic, N. Medhi 2010. “Technology and the diffusion of renewable energy” *Energy Economics* 33 (2011) 648-662
Prodan ,I. 2005. “Influence of research and development expenditures on number of patent applications: selected case studies in OECD countries and central Europe, 1981-2001” *Applied Econometrics and International Development* (AEID) Vol. 5-4
RTE 2013. *Bilan electrique2013*
Sheppard, M. 2013. “Number of Companies in the Solar Supply Chain Set to Plunge This Year” for IHS iSupply January 9, 2013
Solangi, K. H., M. R. Islam, R. Saidur 2011. “A review on global solar energy policy” *Renewable and Sustainable Energy Reviews* 2149-2163 15 (4)
Stiglitz, J. 2006. Interview for the Economist’s view, Wednesday, October 11, 2006 http://economistsview.typepad.com/economistsview/2006/10/joseph_stiglitz.html
The W. K. Kellogg Foundation 2004. *Logic model development guide: Using logic models to bring together planning, evaluation, and action* chapter 1 : Introduction to Logic Models
The World Bank. http://data.worldbank.org/
Timilsina, G. R., L. Kurdgelashvili, P. A. Narbel 2011. *A review of solar energy: markets, economics and policies*. The World Bank
UNCOMTRADE. http://comtrade.un.org/db/, HS Classification, Code 854140 (accessed 29 June 2014)
Vedung, E. 1997. *Public policy and program evaluation*
White, W., A. Lunnan, B. Kulisic 2013. “The role of governments in renewable energy: The importance of policy consistency” *Biomass and Bioenergy* 57 October 97–105
Wholey, J. S., H. P. Hatry, K. E. Newcomer 2004 *Handbook of practical program evaluation* (2nd edition)
Wilson, C. 2012. “Input, Output & Outcome metrics for assessing energy technology innovation” *Historical Case Studies of Energy Technology Innovation* Chapter 24
Xie, H., C. Zhang, B. Hao, S. Liu, K. Zou 2012. “Review of solar obligations in China” *Renewable and Sustainable Energy Reviews* 16 113– 122
Yang, C.-J. 2010. “Reconsidering solar grid parity” *Energy Policy* 38 3270-3273
Zhang, S., Y. He 2013. “Analysis on the development and policy of solar PV power in China” *Renewable and Sustainable Energy Review* 21 393-401
Zhao, Z.-Y., S.-Y. Zhang, B. Hubbard, X. Yao 2011 “The emergence of the solar photovoltaic power industry in China” *Renewable and Sustainable Energy Reviews* 21 (2013) 229–236