Technology Push vs. Demand Pull: The Evolution of Solar Policy in the US, Germany and China

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Abstract: To explain and promote the adoption of new technologies, researchers have debated the relative importance of technology push and demand pull factors (e.g., Schmookler, 1966; Mowery & Rosenberg, 1979; Chidamer and Kon, 1994). Here we examine a crucial problem of contemporary innovation policy — promoting the adoption of renewable energy to reduce anthropogenic global warming — that challenges prior models for large scale innovation adoption (Mowery et al, 2010; Hargadon, 2010). From the policy recommendations of Mowery et al (2010), we develop a typology of technology push and demand pull factors for renewable energy adoption. We use these to analyze a database of solar energy policies from 1978 to 2010 in the US, Germany and China. From this, we suggest additions to the model of technology push and demand pull to explain the success of renewable energy adoption policies.

1. Introduction

An ongoing debate for the timing of adoption of new technologies has been over the relative contribution of two types of factors, broadly categorized as "technology push" and "demand pull." The former factors include both the availability of a new technology, its maturity, and its relative advantage, while the latter relate to the degree of unmet need and the awareness of the new technology. This contrast has been drawn in predictive studies for innovation adoption (Cohn, 1980) and normative recommendations to managers (Abernathy & Clark, 1985). For public policy research, the relative importance of these two categories have either led to efforts to support R&D and other technology development, or to encourage demand through subsidies and other incentives (e.g. Mowery & Rosenberg, 1979; Elder & Georghiou, 2007; Nemet 2009).

A current example that has renewed this debate has been over policies to promote the deployment of renewable energies. While such policies are often justified in terms of economic development, the recent push has come due to increased concerns about global warming attributed to greenhouse gas emissions from fossil fuels (e.g. Hargadon, 2010; Mowery, Nelson and Martin, 2010). The challenge is particularly daunting because “The scale of this transformation dwarfs that of most prior problems of technology policymaking. Success requires the development, commercialization, and diffusion of many ‘suites’ of complementary energy technologies throughout society.” (Huberty & Zysman, 2010, p.1027)

Here we review the prior research on innovation as it relates to the technology push vs. demand pull debate, as well as the issues that have been previously identified for the adoption of renewable energy. Using Mowery et al (2010), we develop a typology of push and pull policy categories for RE adoption. We then use this to code data on more 200 policies from 1975-2010 related to RE adoption for three major economies: US, Japan, China and Germany. From this, we suggest that the theoretical model of technology push vs. demand pull is incomplete in explaining the adoption of renewable energy, and suggest the role of generic complementary assets (specifically financing) as a crucial supply push factor that should be considered in renewable energy and other innovation policies

2. Push and Pull Factors in Promoting Innovation Adoption

The debate over the relative importance of technology push and demand pull dates back almost 50 years (Griliches & Schmookler, 1963; Schmookler, 1966; Mowery & Rosenberg, 1979; Scherer, 1982; Jaffe, 1988; Chidamer and Kon, 1994).[1]

[1] The debate tends to assume “a linear model of the innovation process with science at one end and markets or users at the other.” (Chidamer and Kon, 1994: 95). For a rare exception, see the systems perspective of Edquist and Hommen (1999).

Determining the relative importance of these two factors has two major implications. The first is the causal or explanatory, i.e. determining which factor is more important in explaining the successful (or failed) adoption of a new technology. Flowing from this is the second or normative dimension: what policies should a government adopt if it wishes to promote technological progress and the consumer (or producer) benefits that accrue from such adoption.

Insert Table 1 here

2.1 Technology Push

The arguments for technology push contend that whether at the level of a specific inventor or firm (Abernathy & Clark, 1985) or at the aggregate level of an industry (Utterback, 1974), it is the rate of technological progress that determines the adoption and impact of new technologies. In most cases, the importance of industrial R&D is dependent on (or even subordinate to) the role of basic science in enabling this progress.

Perhaps the earliest advocate of this view was Schumpeter, who in his entrepreneurial (Mark I) and corporatist (Mark II) theories argued that radical and incremental innovation expand the base of technology which displaces existing technologies and firms. Some versions of this perspective adopt a weak form of technological determinism, assuming the direction (if not rate) of technological progress to be inevitable and perhaps even exogenous to the efforts of individual firms (Schumpeter, 1934, 1942; Nelson & Winter, 1982; Jaffe, 1988; Chidamer and Kon, 1994; Malerba & Orsenigo, 1996).

Some supporters of this perspective have made narrower arguments. On the one hand, the ability of a firm to deploy radical innovations may depend on a configuration of internal competencies to support a technology push approach (Abernathy & Clark, 1985). On the other hand, the interest of buyers in using a technology may depend on the cumulative incremental improvements in cost, features or quality (Mowery & Rosenberg, 1979). Still other researchers have examined the interdependencies within technology push. For example, Meyer (2000) concluded that within a technology push approach, technology can pull science or that science can push technology.

2.2 Demand Pull

The idea that new technologies are not endogenously created, but in fact are shaped by the nature of demand can be traced to the work of Jacob Schmookler (Griliches & Schmookler, 1963; Schmookler, 1966). As Scherer (1982: 225) put it, "Schmookler's main contention, contrary to the prevailing emphasis on changes in scientific and technological knowledge, was that demand played a leading role in determining both the direction and magnitude of inventive activity." Schmookler (1966) and Scherer (1982) found that demand (as proxied by capital investment) led technical invention (as measured by patents).

In a review of 17 studies of innovation adoption, Utterback (1974: 621) concluded:

> Market factors appear to be the primary influence on innovation. From 60 to 80 percent of important innovations in a large number of fields have been in response to market demands and needs. The remainder have originated in response to new scientific or technological advances and opportunities.

While studies of the impact of commercial or consumer demand on technological progress can inform public policy, a more direct link can be found in the role of government procurement. Edler & Georghiou (2007) discussed how EU governments could use public procurement to support national technology development and commercialization efforts.

In response to such studies, in their critique Mowery & Rosenberg (1979: 105) argued that the role of demand was "overextended and misrepresented." Even at that early stage in the development of renewable energy, they concluded

> The point is that in certain areas, such as alternate energy or antipollution technologies, industries may simply lack sufficient R&D resources or the necessary market-generated incentives. (Mowery & Rosenberg, 1979: 148).

2.3 Push and Pull Factors in Promoting Renewable Energy

The role of technology push or demand pull has been identified in a small number of studies related to renewable energy adoption.

The strongest support for supply push comes from Mowery et al (2010). Both directly for renewable energy adoption and through analogous reasoning of successful U.S. and U.K. technology policies, they focus on the role of the national government in funding technology development to enable subsequent adoption.

However, there has been a recent emphasis on the use of demand-side policies. For example, an official U.K. blue-ribbon commission argued that strict regulatory standards to mandate the use of renewable energy would "stimulate innovation by reducing uncertainty for innovators" (Stern, 2006, p. 378). Similarly, Hargadon (2010: 1025) argued that "Demand-side policy incentives are considerably more effective at promoting the innovation and diffusion of renewable energy than R&D investments," and in particular rejected the linear model from basic science through R&D to manufacturing and deployment.

In one recent empirical study, Nemet (2009) focused on the role of demand-side policies in promoting wind generation in California. He identified investment tax credits, production tax credits, guaranteed tariffs, and guaranteed market for electric power as key factors in making California the world's leading market for wind power in the 1970s and 1980s. However, he concluded that promoting renewable energy adoption requires a complimentary mix of both technology push and demand pull policies.

3. Research Design

Our study focuses on three countries: the U.S., Germany and China. In some 60 years since the first practical solar cell was invented, domestic policies have enabled three countries to play a leading role in the deployment of solar energy. Based on the needs of its (government-funded) aerospace industry, United States was the technological leader and provided early niche markets from the 1960s until the 1990s. Through policy innovation, Germany has been the largest market in the world during the 21st century to date. Finally, with massive public investment in manufacturing companies at a time of credit contraction in the west, by 2009 China led the world in PV manufacturing capacity, as measured both by annual output and capital investment.

3.1 Data Sources

The present paper is based on secondary data. We accessed an open access database on global solar policies of the International Energy Agency (IEA).[2] The database contains structured data for describing existing RE policies. A large set of data fields is offered such as country, policy name, year of implementation, policy status, links to other policies, funding, objectives, policy type, a detailed description, and links to further information. The policies in the database are categorized into 7 categories listed in Table 2. The database allows filtering of polices according to countries, technologies, types etc.

Insert Table 2 here

Based on our research goals, we have selected three countries: US, Germany, and China. We selected only policies that directly relate to solar PV; this includes both solar-specific policies as well as broader RE policies which cover solar PV (among other technologies). The search resulted in overall 97 matches, including 57 US, 27 German, and 13 Chinese policies (Table 3).

Insert Table 3 here

3.2 Coding

In order to answer the question to what degree the Mowery Nelson and Martin (hereafter MNM) concepts of RE policies are already being used and which role technology push and

[2] Online at http://www.iea.org/textbase/pm/

demand pull are playing in this context, a coding system was derived which reflects the general design principles for technology policies that might contribute to combating climate change as proposed by MNM.

The authors discuss new models for energy-related technology policies to combat global warming but they do not refer to specific technologies, like e.g. wind or solar based electricity generation, energy-efficiency or energy saving technologies. They deduce their guidelines from a historical analysis of US and UK policies from the fields of agriculture, biomedical research, and information technology. Based on best practices as well as insufficiencies of public policies throughout the second half of the last century, different policy principles are discussed in the implications section of their paper (MNM, pp. 1019-1022). These principles can be grouped into three classes: technology push principles, demand pull principles and conditions of policy application.

The current analysis is thus a first step towards operationalizing their design principles as some kind of policy assessment system. Therefore, to operationalize and apply these principles to the empirical data found in the IEA database, a coding system comparable to approaches of qualitative content analysis was developed in an iterative process of coding and re-coding (Eisenhardt, 1989).

We identified 15 separate principles in the MNM policy proscriptions that we grouped into the three aforementioned categories: technology push (T1-T4), demand pull (D1-D4) and conditions of policy application (C1-C4). We then applied the resulting framework (Table 4) to code the IEA data.

Insert Table 4 here

In parallel to the IEA database, we developed from published sources (in the respective national languages) a chronological history of the major milestones of the solar policy in the three countries. We used these histories to supplement our analysis below of the IEA data, but did not explicitly code events or policies outside the IEA data.

4. US Policies

Consistent with other evidence, the IEA database shows that the US has the longest history of solar policies (Figure 1).

Insert Figure 1 here

Beginning in 1978, three periods of policies can be distinguished.

- 1978-1986. This initial period established some basic policies that remained unchanged for years, but had limited impact on deployment.
- 1992-2004. This long period saw nearly annual changes to renewable energy (RE) policies, but (except at the state level) most were incremental in nature.
- 2005-present. This period has the greatest activity and impact, particularly in 2005 (with the *Energy Policy Act of 2005*) and in 2009 (with the dramatic increase in spending from the *American Recovery and Reinvestment Act*).

Overall, most of the policies were neutral to various RE technologies (C3). Many of the policies were active in the long-term (C1), with the important exception of financial subsidies for adoption (D2).

4.1 Technology Push

The first US policies were technology push policies. In 1974, the Federal government established the Solar Energy Research Institute and from 1975-1986 the US government spent $235 million for R&D in the Low-Cost Silicon Solar Array project.

The earliest RE policy (for any country) in the IEA database is the *Solar Photovoltaic Energy Research, Development and Demonstration Act,* which was enacted in November 1978 to fund programs for Research, Development and Demonstration (RD&D) on solar photovoltaic energy with a budget of $105 million for the first year. The bill emphasized dramatic improvements in technology rather than commercialization (T1-c). In fact, in signing the bill President Carter said the technological goals were “very optimistic” and “may be unrealistic” (Carter, 1978).

Throughout the 1970s and 1980s, the Federal government funded public and industry research through the Solar Energy Research Institute, which in 1991 became the National Renewable Energy Laboratory. A major goal of having a central solar energy lab was broad dissemination of government funded R&D (T2). Other policies aimed at broad dissemination include the international activities (from 1999 onward) of the Department of Energy's Office of Energy Efficiency and Renewable Energy — which sought cooperation between the US and other national governments (C4). Although not anticipated by the MNM framework, these and other efforts included dissemination of both technology and knowledge of non-technological best practices.

The use of prizes (T3) was most evident in the 2002 legislation creating *Solar Decathlon,* a biennial competition for college students from around the world. However, because the contestants paid their own construction costs and received only non-monetary recognition, the public display of the competing entries was consistent with a demonstration project (T4).

Demonstration projects were in fact common from the earliest period, but the pace picked up after 2005. Among the most visible was President Bush’s *Solar America Initiative* (2006-2009), which allocated $1 billion for a combination of research, demonstration projects and the elimination of adoption barriers. This included support for 25 local cities seeking to spur adoption.

Finally, the rate of Federal spending on technology push R&D strategies increased dramatically (if temporarily) with the 2009 *American Recovery and Reinvestment Act*, which provided $80 billion in RD&D funding for RE and other "clean" technologies. However, only 2% ($1.6 billion) was spent funding direct research into alternative energies that include solar.

4.2 Demand Pull

One of the key goals of MNM (C1) is long-term and stable support for RE policies. While Mowery et al (2010: 1021-1022) lament that "a crucial weakness of U.S. energy R&D policy historically has been the instability of program goals and funding," the US data suggest that the problem has at least as serious for demand pull policies. The 33-year history in the IEA database (confirmed elsewhere) document a series of one-time and temporary tax credits, accelerated depreciation and other financial incentives that expired in 1-3 years. (In some cases, the temporary credits were renewed on an annual basis.)

When the US launched its initial R&D policies in 1978, it also enacted two significant demand-side policies. The most enduring was the *Public Utility Regulatory Policies Act* (PURPA), which established a basic principle for distribution of distributed RE sources: the policy required utilities to buy power from independent companies at a competitive price.

The other major demand policy that year was the *Energy Tax Act of 1978,* the first financial incentives for adoption (D2) which provided tax credits for purchase of RE equipment by private and business users. Additional text benefits were provided through accelerated depreciation in the *Economic Recovery Act of 1981.*

However, the broadest and most enduring U.S. demand policies of the 20th century came with the *Energy Policy Act of 1992.* The policy introduced investment credits, production tax credits and production incentives (per kWh) for various RE technologies including solar PV (D2). As subsequently implemented, the policy also used government procurement (D4) , both directly and through support of tribal and rural agencies.

The third period (2005-2010) is the most dynamic era of US solar policies accounting for 18% of the period covered by the IEA database but roughly 30% of total US policies. The period starts with the *Energy Policy Act of 2005* and with several related policies. These include executive orders to federal agencies for addressing government procurement (D4) and loan guarantees for clean technologies (D2). This revised act is also the beginning of a shift where eligible technologies are broadened from RES towards "clean energy" technologies including new nuclear, clean coal, and carbon capture and storage. With this shift technology diversity is further increased (C3), however to an extent which goes beyond traditional definition of RE. The *Energy Independence and Security Act of 2007* also includes 50% matching grants (D2) for the development of RE generation projects.

The largest scale support for RE came from the 2009 *American Recovery and Reinvestment Act,* the $787 billion stimulus package signed by President Obama during his first month in office. In addition to RD&D support, the $80 billion for clean technologies included $30 billion in tax credits. The program also provided more than $1 billion in direct grants for "clean energy" projects (including solar), and more than $8 billion in loan guarantees for PV factories and utility-scale solar generating plants.

4.3 State Level Policies

Among US renewable energy policies, a significant proportion of the policies since the mid-1990s have been state-level policies (Figure 2).

Insert Figure 2 here

Most of the state-level policies are demand pull policies that use regulation to set renewable energy performance targets (D1), through a mechanism called the *Renewable Portfolio Standard (RPS)*. Under the RPS, states set a quota for renewable energy procurement from investor-owned (and sometimes municipal) electricity distribution companies. While the first such RPS policy was established in 1983, most states adopted such policies after 2000; these states include Massachusetts, California, Colorado, Nevada and Maryland. To reduce fossil fuel consumption, some policies also included energy efficiency efforts, whether integrated with the RPS (e.g. Illinois) or through separate energy efficiency mandates (California's Title 24).

To support state efforts, in 1996 the Federal government created the *State Energy Program* where funds to states were given for a demand pull programs including communications and outreach activities, technology deployment, and accessing new partnerships. The policy is an example of both centralized leadership (C2-b) and decentralized authority (C2-a). In 2005, other policies increased the federal-state collaboration on RE policy making (e.g. *State Utility Commission Assistance*; *State Climate and Energy Program*). Included are such measures as tools for RE situation analysis, best practice handbooks on policy making, and partnership programs for discussing and exchanging best practices.

Finally, some states instituted direct financial subsidies (D2) for installing solar (or broader RE) generating capacity. The largest of these was the *California Solar Initiative* (2007), a 10-year program that increased electricity rates to pay $2.2 billion in rebates for the purchase of decentralized PV generating equipment.

5. German Policies

Germany's attempts to support renewable energies systematically through policies reach back to the mid 1980s. During the decades this support has been dominated by demand side oriented measures while technology focused programs were only sporadically implemented, but also showing a tendency of stabilization in the last decade. Interestingly, the budgets from a broad *Market Incentive Program* were devoted to the renewable energy research funding budget of the Federal Ministry for the Environment – with solar technology research being the primary beneficiary (BMU, 2010a). However, this does not point to some kind of policy paradigm change; it is rather an indication of how the German policy makers try to combine different policy principles such as decentralized authority (C2-a), centralized leadership (C2-b), and technological diversity (C3) by means of applying technology and demand oriented policies in a complementary manner.

Insert Figure 3 here

With a focus on photovoltaics the outcome of this policy style can be summarized as follows (BMU, 2010b; BSW, 2010): Suppliers of silicon, wafers, cells, and modules had sales of €8.6 billion in 2009 (€0.2 billion in 2000), of which 47% were based on exports. According to the German Solar Association (BSW) jobs in this industry grew twenty-fold from 3,100 in 2000 to 63,000 in 2009, outpacing all other renewable energy technologies. Moreover, BSW expects 100,000 jobs by 2020. Cell production capacities grew from 16 MW in 2000 to 2,456 MW in 2009, and module production capacity was 2,065 MW in 2009; in 2000 this was 15 MW. Nevertheless, due to the extensive demand incentives Germany is a net importer of PV equipment (Frondel et al., 2008) (mainly modules, while machinery to produce this equipment is typically a German export hit).

5.1 Demand Pull

After having installed Europe's first PV system in 1983, seven years later Germany launched the *1,000 Roofs Program* which provided direct government subsidies for 2,000 systems between 1 and 5 kW with a total capacity of 5.3 MW.[3]. It was followed in 1999 by the *100,000 Roofs Program*, a PV-specific KfW[4] Promotional Bank loan scheme that stimulated the installation of about fifty thousand systems with a combined capacity of 261 MW, requiring preferential loans of about €560 million (both D2).

Already before the *100,000 Roofs Program*, in the early and mid 1990s, a set of different demand pull policies, mostly financial incentives, subsidies and regulatory instruments, was implemented. Preferential loan schemes from the KfW (beginning in 1990) and the *Electricity Feed-In Law* from 1991 (*Stromeinspeisegesetz, StrEG;* discussed below) were the instruments with the highest impact on the diffusion of solar PV in this period (D1, D2, D3). The KfW granted loans of €10.7 billion in total under the *Environment and Energy Saving Program (ERP)* (D2). The program started in 1990 and supported a broad range of RE technologies until it ended in 2008. Although the main beneficiary was wind energy, the share of loans for PV installations grew increasingly important, especially in the final years of this program. In 2009 the *ERP* was consolidated with other loan schemes to form the new *Renewable Energies Program* which also superseded the former *Producing Solar Power, Environment,* and the *Renewable Energy Programs.* Under the *Producing Solar Power Program* (2005-2008) €784 million was granted for small PV systems up to € 50,000, resulting in 199 MW of new installations (all D2).

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3 There are several approaches to measuring solar panel output. In this paper, we use the most commonly used measure: the peak panel (DC) output, which differs from the actual output due to differences in the incoming radiation and conversion losses from DC to AC.

4 The KfW is the German Kreditanstalt für Wiederaufbau, a state-owned bank with the primary purpose to support debt capital for different kinds of economic development programs.

Another type of support can be labeled *Market Incentive Program* (MAP) (D2). *MAPs* include investment support through public investment additional, reduced interest rates or tax incentives. However, the latest MAP provided by The Federal Office of Economics and Export Control (BAFA) includes solar thermal (for heating) but not solar electricity.

5.2 Demand Pull: Feed-in Tariffs

The major German policy promoting renewable energy was the Feed-in-Tariff (FiT), established by the *Electricity Feed-In Law* of 1991 (in German: *Stromeinspeisegesetz, StrEG*) and strengthened with the 2000 *Renewable Energy Sources Act* (*Erneuerbare Energien Gesetz, EEG*). The StrEG and EEG are demand pull policies that incentivize the purchase of electricity generating equipment by requiring electric grid distribution companies to pay an above-market price for the generated electricity (D3). By guaranteeing that price for 20 years, the FiT offer a comfortable security for long-term investments and returns.

The 1991 *StrEG* provided the first FiT in the world, and also ensured privileged grid access and obliged grid operators to pay premium prices for green electricity. This law covered bioenergies, such as electricity from biogas power plants, wind-, and hydropower, and also solar energy. As the *EEG* today, the *StrEG* was not based on public budgets, but on payments from the grid operators which then charge their customers.

The *StrEG* calculated the remuneration on an annual basis as a specific percentage of the average electricity price end customers had to pay in the previous year. Wind and solar power received 90% of the mean electricity price, while hydro, biomass and biogas power plants were granted 65% or 75% (depending on installed capacity). The remuneration principle was changed for different reasons as the *EEG* replaced the *StrEG* in 2000. Now, the premium prices are calculated on base of actual technology-specific electricity generation costs which were regularly reviewed in 2004 and 2009 (D3), followed by additional adjustments in 2010 and 2011 which mainly adapted PV tariffs in order to moderate the increasing growth rates of newly installed capacities. Besides these revisions the technology-specific remuneration is subject to an annual reduction.

The tariff basically differentiates PV installations on buildings from those that are ground mounted. Moreover, in 2009 a premium for direct electricity consumption (instead of grid feed-in) was implemented as new category including different tariffs depending on installation capacity and share of direct consumption. This tariff accounts for the additional cost of PV that producer-consumers have in comparison to buying electricity from utilities (9.5 to 16.7 Eurocents premium in 2011). After two unscheduled reductions in July and October 2010, the PV tariffs for fed-in electricity from installations on buildings range from 21.6 to 28.7 Eurocents, while in 2004 the range was 54 to 57.4 Cents. This category includes tariffs for different installation sizes (28.7 Cents for facilities below 30 kW; 27.3 Cents from 30 to 100 kW; 25.9 Cents above 100 kW; and 21.6 Cents above 1,000 kW). The ground mounted category does not distinguish between capacities but classifies burdened fields (22.1 Cents), farm land and other fields (21.1), whereas installations on farm land were excluded in July 2010 due to political concerns about trends in land usage.

Although the demand oriented policies seem to fulfill at least all policy conditions which were derived from Mowery et al., the main characteristic is a long-term orientation to embed and nurture national demand (C1) (e.g. the FiT logic and privileged grid access for renewables are in effect for two decades, thus allowing the different actors to orientate their activities towards the according support mechanisms, even if the law changed several times in the meantime). The resulting demand can choose from a broad set of technologies, ranging from biogas, to wind, to solar, or from liquid fuels, to electricity and heat (C3). But remarkably, in each of these technological fields lead technologies evolved which might be rather due to industrial and market dynamics, biased by demand from abroad (e.g. three-wing wind turbines, crystalline vs. thin-film photovoltaics, biogas direct combustion vs. biogas grid feed-in).

5.3 Technology Push

For technology push policies, only the *BMU Research Funding Scheme* has a significant scale. The program funds research projects carried out by companies, universities, other research institutions, and public companies (T1-a).

With regard to the goals of innovativeness, competitiveness, and exports of German manufacturers especially the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) follows a very offensive research policy. Of the total renewable energy research project funding being on hand of the BMU, great shares are dedicated to PV: On an annual basis, PV received between 26 and 44% of new grant approvals from 2006 to 2009; more than any other renewable energy technology (BMU, 2010a).

The BMU strategy is based on a broad and at the same time also focused approach of supporting the German PV industry. On the one hand, the setup of diverse institutional arrangements was supported by the BMU to bridge general gaps between laboratory research and industrial production (T1-c, T4; e.g., the Photovoltaic Technology Evaluations Center, PV-TEC) and to support the realization of economies of scale and scope (e.g., investment programs or industrial cluster support in the "Solarvalley Mitteldeutschland"). Policies like these aim at shortening industrial innovation cycles and increasing global competitiveness of German manufacturers. On the other hand, the Government also focuses on very specialized R&D-efforts; e.g., to increase the performance of specific crystalline or thin-film cell types (T1-c, T4).

Here, the BMU supports single companies but also follows a principle of transparency and publicity to speed up the diffusion of such research outcomes amongst the German PV industry (T2).

The primary purpose is realizing cost reductions on the supply-side in order to secure global top market positions of German technology producers. Therefore, the state pays up to 50% of research project costs under *The Fifth Energy Research Program*. This type of funding is available for selected fields of PV research, such as silicon wafer and thin film technologies, system technologies (e.g. decentralized applications), concentrated photovoltaics (CPV), and different cross-sectional technologies (T1-c). The BMU research budget for renewable energies increased significantly in 2005 as funds from the *MAP* were assigned and in the following the budget continually increased due to the *Government's High-Tech-Strategy* and *Climate Change Policies.* Thus, in 2009 €118 million were approved for renewable energy research projects, of which PV got about 26% (€31 million). On average, PV received nearly 39% of fund payments from 2006 to 2009.

Regarding policy conditions, the German technology push measures are less characterized by long-term programs (which would be C1). Especially technological diversity (C3) and a balance of decentralized authority (C2-a) and centralized leadership (C2-b) are specific features of the German RD&D approach.

6. Chinese Policies

The Chinese PV industry is export driven, with about 90% of the industry outputs exported abroad.[5].

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[5] Interview with senior official, China Ministry of Science and Technology, May 27, 2011.

The history of Chinese solar policies is a recent one with a rather limited set of policies implemented, however, with high dynamic within the last decade (Figure 4). Viewing increasing awareness of global warming and international support for renewable energy development, China is experimenting a wide range of policy support to RE, including PV policies. We can see a mix of sporadic demand pull policies, limited technology push policies, and some broader level policy support to the PV industrial development.

Insert Figure 4 here

6.1 Demand pull policies

Most of the demand pull policies in China fall in our categories of regulatory performance targets (D1) and targeted financial incentives (D2). The relatively abundance in regulatory performance targets policies to a degree reflect the Chinese government's increasing focus on sustainability issue and efforts to align with the international goals.

The history of the regulatory performance targets (D1) related solar policies goes back the earliest RE policy seen in China- *the Brightness Programme*. This program aims to electrify towns and villages in remote areas by using wind, solar and other renewable energy sources, and remains in effect.

The first overarching policy for encouraging domestic demand for RE was the *Renewable Energy Law* (2006) by which RE has become the preferential area for energy development. Therefore grid access has been guaranteed and national targets for energy production from RE sources have been set. This policy is at the same time the starting point for very dynamic RE policy development in China. One year later (2007) the *National Climate Change Programme* set a general strategy of R&D and diffusion in energy efficiency and renewable energies technologies (amongst others), for combating climate change. The same year the government set medium and long-term goals for capacity installation for each RE technology: solar PV 1.8 GW;

hydro 300 GW. Three years later the renewable energy law was modified with adjusted premiums and additional research programmers in off-grid RE solutions.

Only in 2003 the China first created preferential tax policies to encourage foreign investment into RE enterprises and thus to source foreign knowledge on production and installation. This was the first policy that focused on targeted financial incentives (D2), offering income tax cuts for the producers and consumers of renewable energy, as well as a reduction of the import tax for "green" equipment.

Since 2008, the national and provincial governments established larger purchase subsidies, with Shangdong Province pioneering such polices. The *Shandong Province Village Renewable Energy Regulations* provides subsidies for specified renewable energy technologies in farming villages. The *One Million Roof Sunshine Plan* in Shandong Province in 2008 is another example of targeted financial incentives policies. It targets use of solar power and geothermal power in buildings. This polices was followed by the national level *Solar Power Roof Plan*, proposed in March 2009. The subsidy standard is 20 yuan/W, for installations with capacity of 50kW or more. For government invested projects, the responsible government can get 50% refund for all installation related costs. However the overall subsidy amount is limited to ¥ 2.5 billion, limiting installations under the programmed to around 180 MW[6].

The *Golden Sun Programme* was proposed in July 2009, with a goal of 600MW of installed solar PV capacity across China. The program has provided grants both at national and provincial levels: at the national level grants are given to subsidize capacity installation, while provincial grants are used to support preferential electricity tariffs. The minimum capacity requirement for

[6] Christian Zeppezauer and Connie Carnabuci, Oct 9, 2009. "A New Revolution: China Hikes Wind and Solar Power Targets". See **http://www.renewableenergyworld.com/rea/news/print/article/2009/10/a-new-revolution-china-hikes-wind-and-solar-power-targets**

each supported project is 300-kW and the product is required to operate for at least 20 years. The program is viewed as one of the demonstration projects that the Chinese government has put in place to promote PV or other RE development. For the similar demonstration projects in each province, the central government subsidizes up to 50% (on-grid) or 70% (off-grid) of the entire installation costs. Total capacity used as demonstration project cannot pass 20MW in each province during 2009-2011. In 2010 the program has been complemented with a program specifically encouraging building integration of solar PV (the *Building Integrated Solar PV Programme*).

In addition to the subsidies for purchasing generating equipment, the central government also requires that electricity companies in that demonstrated area purchase the extra capacity generated by the demonstration project at unit price similar to power generated from other sources (such as coal). For instance, the manufacturer Zhengtai Sun Power Company (English Name: Astronergy) is a beneficiary of such project. It implemented six PV projects with a total capacity of 7.86MW. The company will receive subsidies in the following 2 to 3 years.[7]

Local governments have followed the examples of the demonstration projects. For example, the city of De Zhou in Shandong Province has the goal of becoming a solar power based city. The Shanghai government plans to build 100,000 roof power generation systems, with total capacity reaching 400MW. Beijing government also promotes the PV based road lighting system in its surrounding counties.

“Currently the lowest cost of PV electricity generation worldwide is about 0.54 yuan/kw, the selling price to consumers should be at least 0.87 yuan/kw, adding a reasonable margin for the

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7 www.solar-pv.cn. (news Feb 4, 2010)

electricity generators. However this price is far above what is paid now by Chinese residents", said Yongsheng Chen, Sales Representative in Shanghai for the Switzerland-based Oerlikon.[8]

The charge of 0.87 yuan/kw is twice the amount Beijing residents pay for electricity in 2009[9]. Furthermore, National Development and Reform Commission (NDRC) announced in 2010 that electricity consumption price should be stable for at least 70%- 80% of all residents in China for the next three years to come.[10]

In 2011, the central government is considered a policy to set the price of electricity generated by sun power at 1.09 yuan/kW. Although it is about 3 times as expensive as power generated by coal, it is still not enough to allow Chinese manufacturers to sell their equipment domestically at a profit. Furthermore, the policy is still not implemented.[11]

6.2 Technology push policies

There are a few policies on RE or solar PV targeting at pushing technological development. The national level initiatives targeting at R&D support to PV industries include:

- national "973 plan". Focus on basic research such as research on thin film battery
- national "863 plan". Focus on advanced technology development. Support the commercialization of PV technologies
- national "key projects support plan". Funding are available to research in PV technologies and its commercialization
- industrialization plan. Monetary support for PV related firms such as Suntech in Wuxi.

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8 "Entrepreneurs call on for PV subsidy", 05-04- 2011, URL: 2011 http://www.1solarcn.cn/Chain/Chain60722434.html.

9 http://zhidao.baidu.com/question/109057019.html. 08-04-2009.

10 http://www.cnstock.com/gonggaojd/xxjm/xxjmtop/201010/906405.htm

11 Zhang, Juan. 02-04-2010. "PV policies heated up PV development in China" http://www.solar-pv.cn/article/article_2781.html.

The Renewable Energy Law amendments in 2009 initiated a Special Fund for renewable energy that will finance research and development and support mini and off-grid renewable electricity generation projects in rural and remote areas.

The International Science and Technology Cooperation Programme for New and Renewable Energy in 2008 sought to boost technological development, introduce cutting-edge technologies in the national market, attract overseas scientists and develop exchange programs with international research centers.

6.3 Effect of Broader Policies

Policies at a broad level that do not specifically targeting at RE or solar PV have actually played an important role in PV development in China. These policies are typically made and implemented at the local government level. Local governments have used tax incentives, talent plans and land support policies to attract new ventures including PV firms to the locality.

6.3.1 Local government policies to attract skilled workers

Local governments instituted their own policies to attract skilled local workers, including Chinese nationals returning from education or work abroad. One example was the "530 plan" introduced by the city government of Wu Xi (Jiang Su Province) in May 2006. The city of Wuxi is where Suntech is based. When the founder of Suntech started the firm in 2001, the city government helped Suntech raise money of USD 6 million from several established local firms, accounting for 75% of the total shares. The success of Suntech in Wu Xi led to the local policy of "530 plan". The name of the plan came from its goal of attracting 30 top level talented workers within five years. The local government made promises to attract top talent coming to Wu Xi to start businesses. Specific policies include: 1) One million yuan to help business starts; 2) Providing at least 100 sq meters as office space and at least 100 sq meters apartment for personal living, free of rent for the first three years; 3) for certain high tech projects, ¥3 million from the venture investment firm owned by the city; 4) Collateral of ¥3 million for high tech products with clear market demand; 5) spouse employment and child care & education arrangements, etc.[12]

6.3.2 Land policies to support new PV ventures

One example comes from Jinzhou, a city in Liaoning Province, which published "Several rules to promote PV industry development in Jin Zhou" in March 2007. It included land subsidies for PV firms: land that is exempt from the property transaction fee and registration fee; in addition, 50% of the land purchase price can be returned to the PV firm as local subsidy.[13]

6.3.3 Financing Industry Development

A key challenge facing the global solar industry is obtaining the capital necessary to expand production capacity, achieve scale economies and finance inventories. The problem became particularly acute for Western companies after 2008, when the financial crisis made public stock offerings impossible and brought numerous US and European banks to the point of insolvency. With a high savings rate and positive balance of payments, the Chinese central government and its banks enjoyed a liquidity from 2008-2010 that was unmatched by their Western equivalents. Some of this money was provided to fund the expansion of leading Chinese PV manufacturers, including five major firms: JA Solar, LDK Solar, Suntech, Trina Solar and Yingli Green Energy. By one estimate, Chinese government banks provided US $34 billion in finance to the industry, including a $8.9 billion line of credit to LDK Solar (Osborne, 2011).

[12] http://jyrcb.bokee.com/6194229.html. 03-30-2007. "尚德现象"引发引才新政.

[13] http://www.tynfd.cn/bencandy.php?fid=56&id=266 . 11-10-2008. "锦州市加快发展光伏产业基地的若干规定"

As a consequence, in 2010 six of the 15 largest cell manufacturers were based in China, producing 3.6 GW of solar modules that accounted for approximately 40% of the world's production (Solar Magazine, 2011).

7. Discussion

7.1 Contrasting the Policies

In Table 5, we attempt to summarize the prevalence of the various MNM categories across the IEA data for the three countries.

Insert Table 5 here

On the technology push side, the U.S. had the earliest and longest history of publicly funded R&D, but unlike the MNM recommendation of **publicly funded private R&D** (T1a), the Federally funded research emphasized R&D performed in government labs. The use of publicly funded R&D was less common and later in both US and Germany. Several categories were difficult to measure from the policy database, such as the use of public funding for private R&D and the MNM ban on **funding marginal improvements** (T1c), while a public policy database would inherently be unable to measure the level of **private R&D funding** (T1b).

On the demand side, each of the three countries used a different form of **financial incentives** (D2): tax credits in the US, a Feed-in-Tariff for Germany and subsidized loans for China.[14] Both China and the U.S. made use of **regulatory performance targets** (D1) (i.e. RE power quotas). Overall, the U.S. used the broadest range of approaches over the longest period of time.

In terms of conditions, **long-term support** (C1) was found in a much higher proportion of policies in Germany than the U.S. This may relate to differences in the political economy, a broader societal support for RE policies, or the specifics of the US (with its reliance on

[14] Subsidized loans were used in the US starting with the 2009 recovery act, but it's too soon to say whether this is an ongoing policy shift or a one-time intervention.

temporary tax credits) or China (with its relatively recent interest in RE). All three countries had policies that combined **decentralized authority** (C2a) and **centralized leadership** (C2b) — possibly reflecting the size of the respective national economies (#1, #2 and #4). The countries also used a mix of solar-specific and **technology neutral** (C3) policies.

What was largely or entirely from the policies of all three countries?

- **Prizes** (T3): no country offered a monetary prize, although the US offered recognition for college students competing in the Solar Decathlon.
- **Pricing externalities** (D3): as was known to MNM, proposals for a "carbon tax" and other such approaches have been proposed but have proven highly controversial.[15]
- **Government procurement** (D4): while common in other policy arenas, most electric power is procured by electricity companies rather than the government.
- **Global cooperation** (C4): one policy in each country included global cooperation. We believe that the IEA database accurately reflects the tension between economic development and fighting AGW among national governments, but the data might also omit such collaboration if these policies enacted (for example) through bilateral political negotiations.

Finally, we found three common policies that were not articulated in MNM typology:

- **publicly performed R&D** (technology push): such R&D was common in the US system, and explicitly argued against by MNM.
- **non-technological "push" policies**: efforts to supply finance, skilled labor or other supply push factors appear to be overlooked in the MNM framework.

[15] The European Union has announced an Emissions Tracking Scheme that takes effect in Jaunary 2012, but we did not include pan-European policies and this is later than the period of our study.

- **removing adoption barriers:** in the multi-level federal systems of the US and Germany, the national government adopted policies to make it less likely that municipal or state government policies would discourage adoption. (We were not expecting to see such policies in China, which has strong central government control).

7.2 Implications for Energy and Innovation Policy

Mowery, Nelson and Martin (2010) offer a model for how countries can develop policies to address global warming and the shared threat it poses to all mankind. Using more than 50 years of technology and innovation policy from different countries and different sectors — as well as their respective broad expertise as innovation scholars — they suggest best practice that governments should apply to their energy and innovation policies.

Using their recommendations, we abstract them into 15 categories of policy recommendations, which can be classified into technology push, demand pull and broader conditions that apply to both technology push and demand pull. Using our dataset of more than 200 national energy policies, we are able to show how their policy recommendations have and have not been followed by policymakers in three key major markets of the world. We also identify three additional policy categories that are not included in MNM.

Our paper thus provides both a way to operationalize the MNM policy proscriptions and a way to code the conformance of government policies to these proscriptions. It also extends the MNM categories — and suggests the importance of coding sub-optimal policies as well as those that conform to the MNM typology. Finally, it provides a comparison of the RE policy strategies of three major economies used over the course of more than 20 years.

7.3 Extending the Push vs. Pull Debate

Technology push and demand pull are already well-established paradigms when discussing policy approaches towards technology and innovation. We offer two extensions to this research.

First, while conflicting theoretical predictions are made for each, the separation of the two approaches seems to be a theoretical argument, not an implementation one. We found several examples of policies (such as the *American Recovery and Reinvestment Act*) in which a single government action instituted both technology push and demand pull policies. In other cases (such as the three key U.S. solar policies of 1978) the push and pull policies were implemented through separate legislation, but proposed and approved in parallel as part of an overall strategy.

The other key finding is the importance of supply push factors beyond technology. While the previous research has bifurcated technology push vs. demand pull policy choices, our research on the solar industry suggests conditions under which even both are not enough to support adoption. Under conditions which require massive scale and concomitant capital investment, the availability of additional generic or specialized complementary assets are essential to achieve adoption policy goals.

In this case, the provision of financing of production and purchase — whether from the government or through intra-subscriber transfers among electricity users — proved essential for the development of the industry and deployment of RE technologies.

The importance of such assets are hardly new, having been identified by Teece (1986) more than 25 years ago (see also Teece, 2006). However, subsequent research on complementary assets has tended to focused on incumbents that already have such assets — whether the advantages they obtain (Rothaermel, 2001) or how the assets become obsolete (Tripsas, 1997). We posit that the emphasis on such established incumbents in the application of complementary assets — and in industrial innovation more broadly — leaves a blind spot to the crucial role that the development of complementary assets plays in the development of these industries. Because the capital requirements for ramping up renewable energy manufacturing appear to exceed those available even from the most patient venture capital investor (Hargadon and Kenney, 2011), we may be venturing into uncharted territory when studying how new firms and industries are formed in the face of such capital requirements.

More broadly, the role of generic complementary assets has broader implications for the success of technologically-enabled industries. In a multi-industry study of technology discontinuities, Rothaermel and Hill (2005) split industries into those that require generic complementary assets and those that require specialized ones, noting that the latter case — with higher entry and imitation barriers — leads to greater industry profitability than the former.

In the case of solar energy, neither the generic nor specific complementary assets seem to be enough. Startup solar companies have struggled to obtain necessary financing, unless they have a strong domestic market (as in the case of German manufacturers) or direct financial support from the government (in the case of China and more recently the U.S.) Meanwhile, existing energy and industrial companies with strong generic assets (in the form of capital and distribution) have yet to play a significant role in the industry.

7.4 Limitations

This paper has numerous limitations — some in the research design, some in the implementation thus far.

Our study is limited to three countries and one renewable energy technology. In limiting our study to photovoltaic energy, it has been difficult to draw boundaries between PV, other solar or other RE or "clean" energy policies.

While we believe this is the most comprehensive longitudinal multi-country comparison of RE policies to date — using the best multi-country database we are aware of — we are limited by the coverage of that database. In particular, we have yet to come up with a way to supplement our main database with other data sources in a systematic and reliable way.

We thus far have used a single rater for each policy. We have had difficulty coding certain attributes from merely the database information, which may require consulting the actual legislation or published laws to develop an accurate coding. Our count of policy attributes is unweighted, and clearly some policies are better funded or more significant than others (although our data do not include such size measures for all policies).

8. References

Abernathy, William J. and Kim B. Clark (1985). "Innovation: Mapping the winds of creative destruction," *Research Policy,* 14 (1), p. 3-22.

Carter, Jimmy. 1978. "Statement on Signing H.R. 12874 Into Law," Nov. 4. Reprinted in *The American Presidency Project,* URL: http://www.presidency.ucsb.edu/ws/?pid=30122.

Chidamber, Shyam R. and Kon, Henry B. 1994 "A research retrospective of innovation inception and success: the technology-push, demand-pull question," *International Journal of Technology Management,* 9 (1): 94-112.

Cohn, Steven F. 1980. "Industrial Product Adoption in a Technology Push Industry", *Industrial Marketing Management* 9(x): 89-95.

Edler, Jakob, Georghiou, Luke. 2007. "Public procurement and innovation—Resurrecting the demand side," *Research Policy* 36 (7): 949–963

Edquist, Charles and Leif Hommen , 1999, "Systems of innovation: theory and policy for the demand side," *Technology In Society* 21 (xx): 63–79.

Eisenhardt, K. (1989): Building Theories from Case Study Research, The Academy of Management Review, Vol. 14, No. 4, 532–550.

Freeman, C. 1982. *The Economics of Industrial Innovation* (2nd ed.). Cambridge, MA: MIT Press.

Griliches, Zvi and Jacob Schmookler, "Inventing and Maximizing," *American Economic Review,* 53 (September 1963), pp. 725-29.

Hargadon, A. (2010): Technology policy and global warming: Why new innovation models are needed, *Research Policy,* 39 (8): 1024–1026.

Hargadon, A. and Kenney, M. (2011). "Misguided Policy? Following Venture Capital into Clean Technology," working paper, University of California, Davis.

Huberty, M. & Zysman, J. (2010): An energy system transformation: Framing research choices for the climate challenge, *Research Policy,* 39 (8): 1027–1029.

Jaffe, Adam B. 1988 Demand and Supply Influences in R & D Intensity and Productivity Growth, *Review of Economics and Statistics,* 70 (3): 431-437.

Malerba, Franco and Luigi Orsenigo, 1996. "Schumpeterian patterns of innovation are technology-specific," *Research Policy,* 25: 451-478

Meyer, Martin. 2000, "Does science push technology? Patents citing scientific literature," *Research Policy* 29: 409-434

Mowery D & Rosenberg N, 1979. "The influence of market demand upon innovation: a critical review of some recent empirical studies *Research Policy*, 8 (2), p. 102.

Mowery, D. C., Nelson, R. R., & Martin, B. R. (2010). Technology policy and global warming: Why new policy models are needed (or why putting new wine in old bottles won't work). *Research Policy*, 39(8), 1011–1023.

Nelson, R., and S. Winter, 1982, *An evolutionary theory of economic change* (Bellknap, Cambridge, Mass).

Nemet, G. F. (2009). Demand-pull, technology-push, and government-led incentives for non-incremental technical change. *Research Policy,* 38, 700–709.

Osborne, Mark. 2011. "Chinese bank lending to solar firms dwarfs sector funding in 2010, says Mercom Capital," PV Tech, January 20, URL: http://www.pv-tech.org/news/chinese_bank_lending_to_solar_firms_dwarfs_sector_funding_in_2010_says_merc

Rothaermel, FT 2001. "Complementary assets, strategic alliances, and the incumbent's advantage: an empirical study of industry and firm effects in the biopharmaceutical industry," *Research Policy,* 30 (8): 1235-1251.

Rothaermel, Frank T. and Charles W. L. Hill. 2005 Technological Discontinuities and Complementary Assets: A Longitudinal Study of Industry and Firm Performance *Organization Science* 16 (1): 52–70.

Scherer, F. M. 1982. "Demand-Pull and Technological Invention: Schmookler Revisited," *Journal of Industrial Economics,* 30 (3): 225-237

Schmookler, Jacob, 1966. *Invention and Economic Growth,* Cambridge, Mass.: Harvard University Press.

Solar Magazine, 2011 "China on track to become the global center of solar photovoltaic (PV) manufacturing," February 14, URL: http://www.solarserver.com/solar-magazine/solar-report/solar-report/china-on-track-to-become-the-global-center-of-solar-photovoltaic-pv-manufacturing.html

Stern, Nicholas and others. 2006. *Stern Review: The Economics of Climate Change,* Cambridge: Cambridge University Press. URL: www.sternreview.org.uk

Teece, D 1986 "Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy," *Research Policy* 15 (6): 285-305.

Tripsas. M. 1997. "Unraveling the process of creative destruction: Complementary assets and incumbent survival in the typesetter industry," *Strategic Management Journal.*

Utterback, J. M. (1974). "Innovation in Industry and the Diffusion of Technology". *Science,* 183 (4125), p. 620-626.

9. Tables and Figures

Construct	Definition
Technology Push	Both firm R&D and the supply of applicable science & technology (Mowery & Rosenberg, 1979) Machinery and process innovations supplied by machinery producers (Cohn, 1980) "The push argument suggests that innovation is driven by science, which in turn drives technology and application." (Chidamber & Kon, 1994) "The core of the science and technology-push argument is that advances in scientific understanding determine the rate and direction of innovation." (Nemet, 2009)
Demand Pull	Innovations are triggered to satisfy a certain class of needs (Mowery & Rosenberg, 1979) "The pull argument suggests … that user demand is the primary factor and that markets, users and applications are, or should be, the key drivers of innovation." (Chidamber & Kon, 1994) "[D]emand drives the rate and direction of innovation. Changes in market conditions create opportunities for firms to invest in innovation to satisfy unmet needs." (Nemet, 2009)

Table 1: Prior definitions of technology push and demand pull

IEA Policy Types	Instruments covered
1) Education and outreach	• *Advice/Aid in Implementation* • *Best Practice Guide* • *Comparison Label* • *Consultation* • *Endorsement Label* • *Information Dissemination* • *Promotion*
2) Financial	• *Funds to Sub-National Governments* • *Taxes and Tax Incentives* • *Tax Exemption* • *Tax Reduction* • *Tax Credit*
3) Incentives and subsidies	• *Feed-in Tariffs* • *Grants* • *Preferential Loans* • *Rebates* • *Third Party Financing*
4) Policy processes	• *Enhancement of existing policy* • *Institutional creation* • *Project based programs* • *Strategic planning*
5) Public investment	• *Government Procurement Program* • *Infrastructure Investment*
6) Research, Development & Demonstration (RD & D)	• *Demonstration Project* • *Research Program* • *Technology Deployment and Diffusion* • *Technology Development*
7) Regulatory instruments	• *Assessment* • *Auditing* • *Benchmarking* • *Mandates* • *Monitoring* • *Quota Systems* • *Regulatory Reform* • *Standards*
8) Tradable permits	• *GHG Emissions Trading* • *Green Certificate Trading* • *White Certificate Trading*
9) Voluntary agreements	• *Intra-Government* • *Private Sector* • *Private Sector/Government*

Table 2: IEA policy categories and instruments covered

Country/Region	Total RE Polices	Photovoltaic-Specific Policies†	Earliest Policy
Germany	91	20	1985
China	25	9	1996
US	154	32	1978

† Includes solar policies that apply both to solar thermal and photovoltaic systems

Table 3: Policy data from IEA database relevant to solar

Code	Policy design principle	Description and indicator (proxy)	Exemplary statements from MNM	IEA Category
T	*TECHNOLOGY PUSH (6)*	*Funding technological research, development, and deployment directly*		
T1-a	*Industry performing publicly funded R&D*	**Industrial firms are important in performing publicly funded R&D** whilst dissemination of results should be supported to avoid monopolies (-> *T2*). ➢ existence of public budgets for private, industry R&D	"…a significant portion of government R&D funding for the development of climate-friendly energy technologies is likely to support R&D performed by industrial firms. Industry will play an especially important role as a performer of publicly funded R&D in prototype development and testing." (p. 1020)	RD&D
T1-b	*Private investment in R&D*	**Funding should shift from public to private, and private R&D investments should exceed public spending** while technologies advance from basic research to commercialization. ➢ occurrence of private spending and ratio of private to public spending	"…an important challenge for the design of government R&D programs in energy technologies is the development of criteria and processes for identifying where and how public investments can catalyze, complement, and usefully augment private-sector investment in energy technology R&D." (p. 1020)	RD&D
T1-c	*No public funding of marginal improvement*	Public spending should **not support incremental improvement of existing technologies** and instead **focus on the technological frontiers.** ➢ support for basic research and "big leap" approaches with a distance to commercialization	"…established firms or user groups are able to exert a dominant influence over the agenda of public R&D programs … [and] are likely to focus on near-term improvements in existing technologies. [But] public funding for marginal improvements of existing technologies is misdirected. Instead, public support should focus on advancing the technological frontiers." (p. 1021)	RD&D
T2	*Broad knowledge dissemination*	**Broad dissemination of knowledge** means that patenting should be reserved for results close to practical application; licensing should be made available with reasonable royalties. ➢ existence of measures to compel any R&D initiative to disseminate results	"We believe that patenting should be reserved for results that are close to practical application and that patenting of research results whose use is primarily as an input to further research should be minimized … it is essential to maintain a 'pro-dissemination' posture." (p. 1020)	RD&D
T3	*Prize competitions*	Stimulate R&D efforts by means of **rewarding technological achievements through prizes** (which is limited and complicated and should be used selectively). ➢ tendering of prizes for technological breakthrough of climate-friendly technologies	"Prizes … have been recommended as a complement to other instruments of government policy, including public R&D funding, in supporting the development of climate-friendly energy technologies. Prizes are best-suited to the 'technological breakthrough' characterization of innovation …" (p. 1021)	RD&D

Code	Policy design principle	Description and indicator (proxy)	Exemplary statements from MNM	IEA Category
T4	*Demonstration projects and learning in use*	Enable the **set up of demonstration projects** to provide key information for improvement and future research; additionally, **experiences of early adopters** should be widely disseminated and **fed back into R&D processes.** ➢ existence of demonstration project programs and/or measures to feed-back learning in use	"We believe that effective public programs to support the development of alternative-energy technologies should also include mechanisms for the support and encouragement of early trial use of new technologies so that their promise can be evaluated and the necessary improvements identified." (p. 1021)	RD&D
D	*DEMAND PULL (4)*	*Catalyze technological innovation by stimulating basic and increased demand*		
D1	*Regulatory performance targets*	Policies should **drive demand towards alternative technologies through regulated performance targets;** these targets may either be defined as reduced negative impacts or as increased use of alternative technologies. ➢ existence of regulated performance targets either on the technology or user level	"Specific regulatory requirements (e.g. emission or performance targets) or targeted financial incentives (tax credits), may spur the adoption of specific technologies … Supportive price and regulatory policies can significantly enhance the effectiveness of government R&D programs in this area." (p. 1020)	Quota Systems
D2	*Targeted financial incentives*	**Financial and fiscal instruments can be applied to encourage certain behavior,** such as investments, that leads to early adopter or increased market demand (e.g. through feed-in-tariffs, rebates, preferential loans, or tax incentives) ➢ application of financial and fiscal instruments aiming at the stimulation or stabilization of demand	"… the early versions of most alternative energy technologies would be handicapped in direct comparisons with existing technologies … the adoption of the initial versions of more environmentally friendly technologies may require subsidies or other forms of public support for early adopters of these technologies (as in the case, for example, of generous German subsidies for the installation of photovoltaic roof panels…)." (p. 1013)	Incentives & subsidies
D3	*Reflection of full social costs in market prices*	Policies should correct market prices for existing technologies (e.g. coal based power production) which do not **reflect full social costs** (e.g. through taxes on competing technologies; carbon taxes; emission trading schemes). ➢ existence of instruments that modify market prices in order to factor in negative externalities	"Any policy to address global warming must address this failure of prices to accurately reflect social costs, for example, through a tax on carbon or a 'cap and trade' system of emissions targets. [This] is further strengthened by the high probability that prices on fossil fuel carbon emissions will be set too low to reflect the full social costs of these pollutants." (pp. 1013, 1014)	

Code	Policy design principle	Description and indicator (proxy)	Exemplary statements from MNM	IEA Category
D4	*Government procurement*	The **diffusion** (but also the development, -> *T1-a*) **of alternative energy technologies can be spurred by government procurement policies;** government procurement can also be combined with other policies such as prizes (-> *T3*) or demonstration projects (-> *T4*). ➢ existence of public procurement or investment programs aiming at alternative energy technologies	"Government will be an important user of some of the new energy technologies, and public procurement policies can be used to promote certain technologies or applications … governments might be better advised to use procurement competitions to encourage the development of climate-friendly energy technologies that could be implemented in public applications." (pp. 1020, 1021)	
C	*CONDITIONS (5)*	*Modifications to either supply or demand policies*		
C1	*Long-term support*	Instead of one-time technological breakthroughs, **a long-term perspective, as well as stable and credible policy commitments,** is necessary for developing and improving alternative technologies and their adoption. ➢ policies are at least five years in effect and do not change too often or too disruptively	"…public programs should focus on long-term support for the development and improvement of relevant technologies, rather than seeking a one-time technological breakthrough. Stability and credibility are therefore important goals for the design of energy R&D programs, as well as for the demand-side policies …" (pp. 1020, 1022)	
C2a	*Decentralized authority*	**Decentralization of policy programs** spans diverse technologies, industries, countries, users and applications.	"A considerable amount of decentralization is desirable or even essential in an energy R&D program that spans such a diverse array of technologies, industries, countries, users, and applications, and which involves such a wide range of activities." (p. 1021)	
C2b	*Centralized leadership*	A **centralized administrative structure** sets general priorities, monitors progress and evaluates performance.	"…a centralized administrative structure for setting broad priorities, monitoring overall progress, and evaluating performance is a necessary complement to a decentralized program structure." (p. 1021)	
C3	*Technological diversity*	The energy-related **technologies** that are involved in any solution to global warming are extraordinarily **diverse** and will be developed and produced by **firms in many different industrial sectors**. ➢ support for a broad range of renewable energy technologies, applications, and sectors	"An effective R&D program to combat climate change must support the development and deployment of many different technologies that will be employed in a diverse array of sectors …" (p. 1019)	

Code	Policy design principle	Description and indicator (proxy)	Exemplary statements from MNM	IEA Category
C4	Global cooperation	Alternative energy technologies address a global problem but are applied locally; **co-operation of national governments and even international subsidies are necessary** to work on this global-local challenge ➢ definition of international division of labor and measures that cross national borders	"…it is critically important to work out an appropriate division of labor among national governments and to create effective mechanisms for cooperation and coordination. Much more than 'technology transfer' will be required, although support for the global dissemination of information and, potentially, subsidies for other nations…" (p.1022)	

Table 4: Push vs. pull policy proscriptions of Mowery, Nelson and Martin (2010)

Orientation	Code	Policy	US	Germany	China
Technology push	n/a	Public R&D	++	+	+
	T1a	Publicly funded private R&D	?	+	+
	T1b	Private investment in R&D	n.m.	n.m.	n.m.
	T1c	No public funding of marginal improvement		+	
	T2	Broad knowledge dissemination	+	?	?
	T3	Prize competition	?		
	T4	Demonstration projects	+	?	+
Demand pull	D1	Regulatory performance targets	++		++
	D2	*Targeted financial incentives*			
		Subsidized loans	+	+	++
		Purchase rebates and tax incentives	++	+	+
		Feed-in Tariff		++	
	D3	Pricing externalities			
	D4	Government procurement	+	?	
Conditions	C1	Long-term support	+	++	+
	C2a	Decentralized authority	+	+	+
	C2b	Centralized leadership	+	+	+
	C3	Technological diversity	+	+	+
	C4	Global cooperation	?	?	?

Code: + policy is used; ++ policy used frequently or particularly important. N.m.: not measurable

Table 5: Policy instruments used in three countries

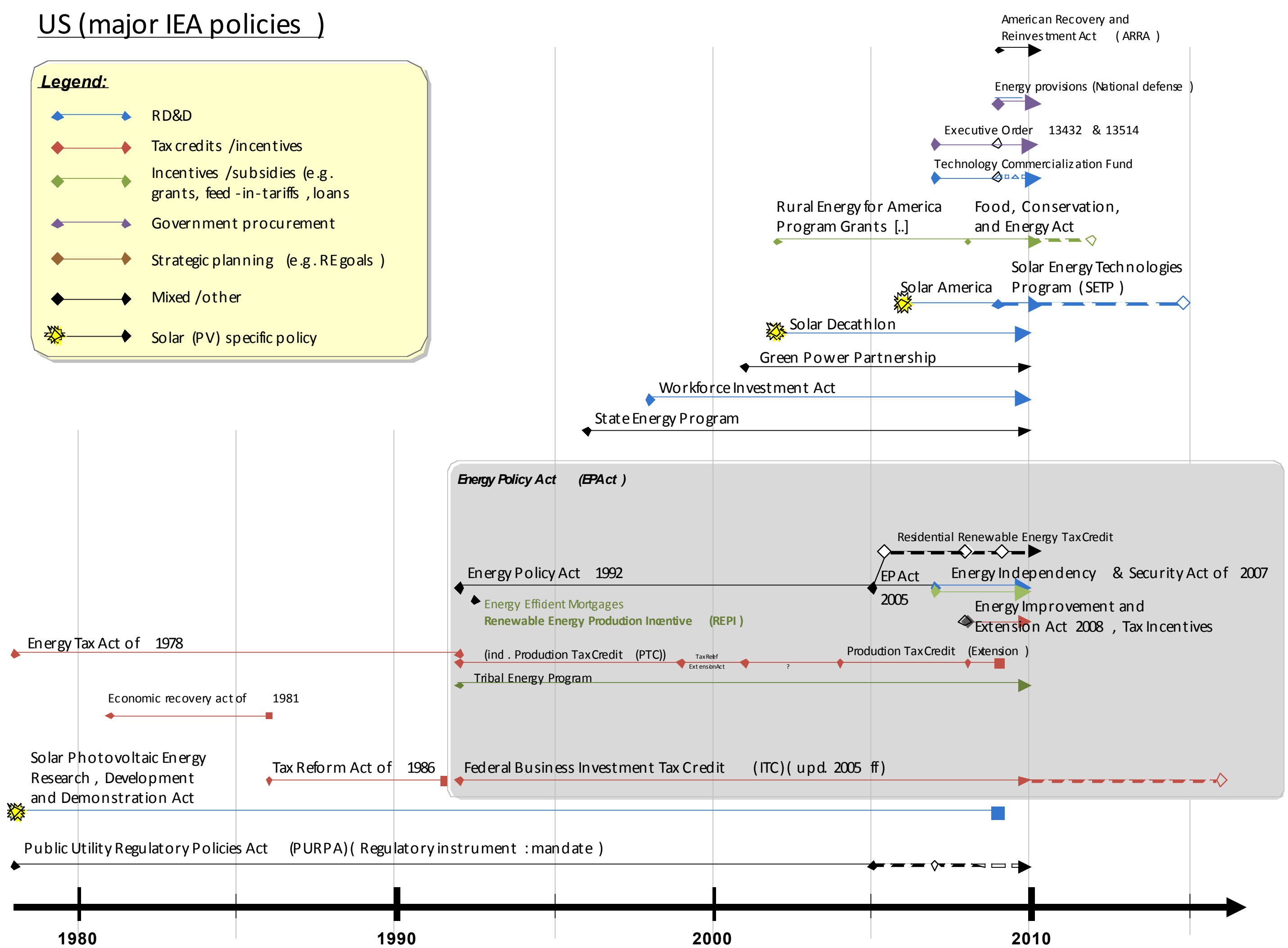

Figure 1: Policy milestones in US

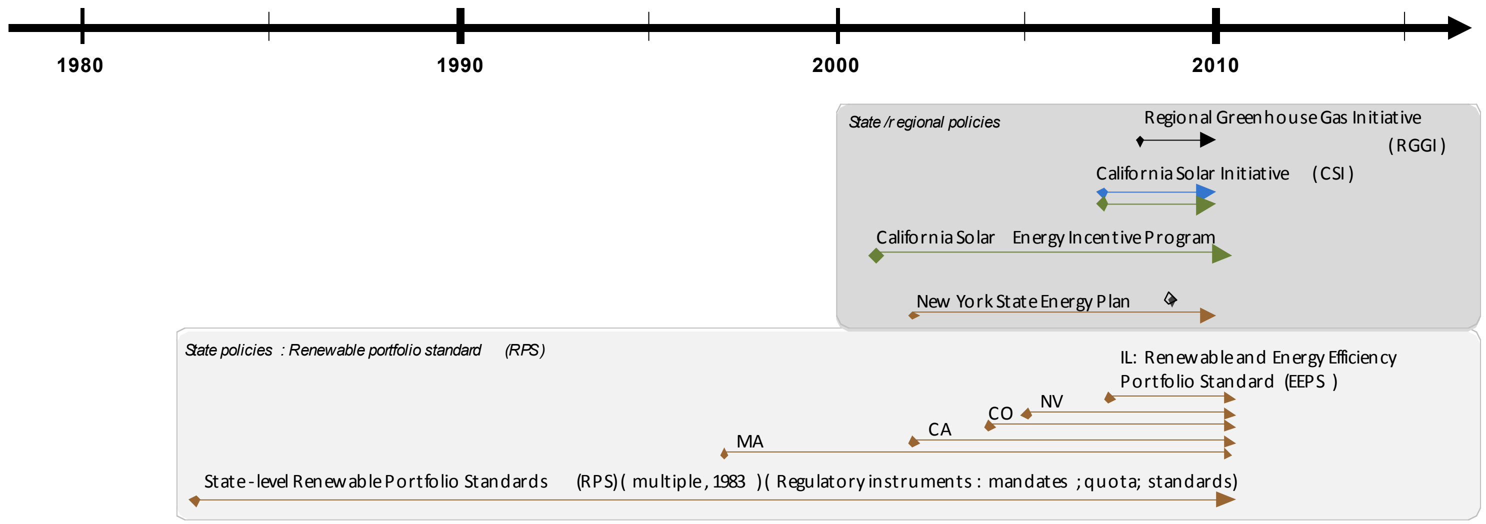

Figure 2: State-level policy milestones in the US

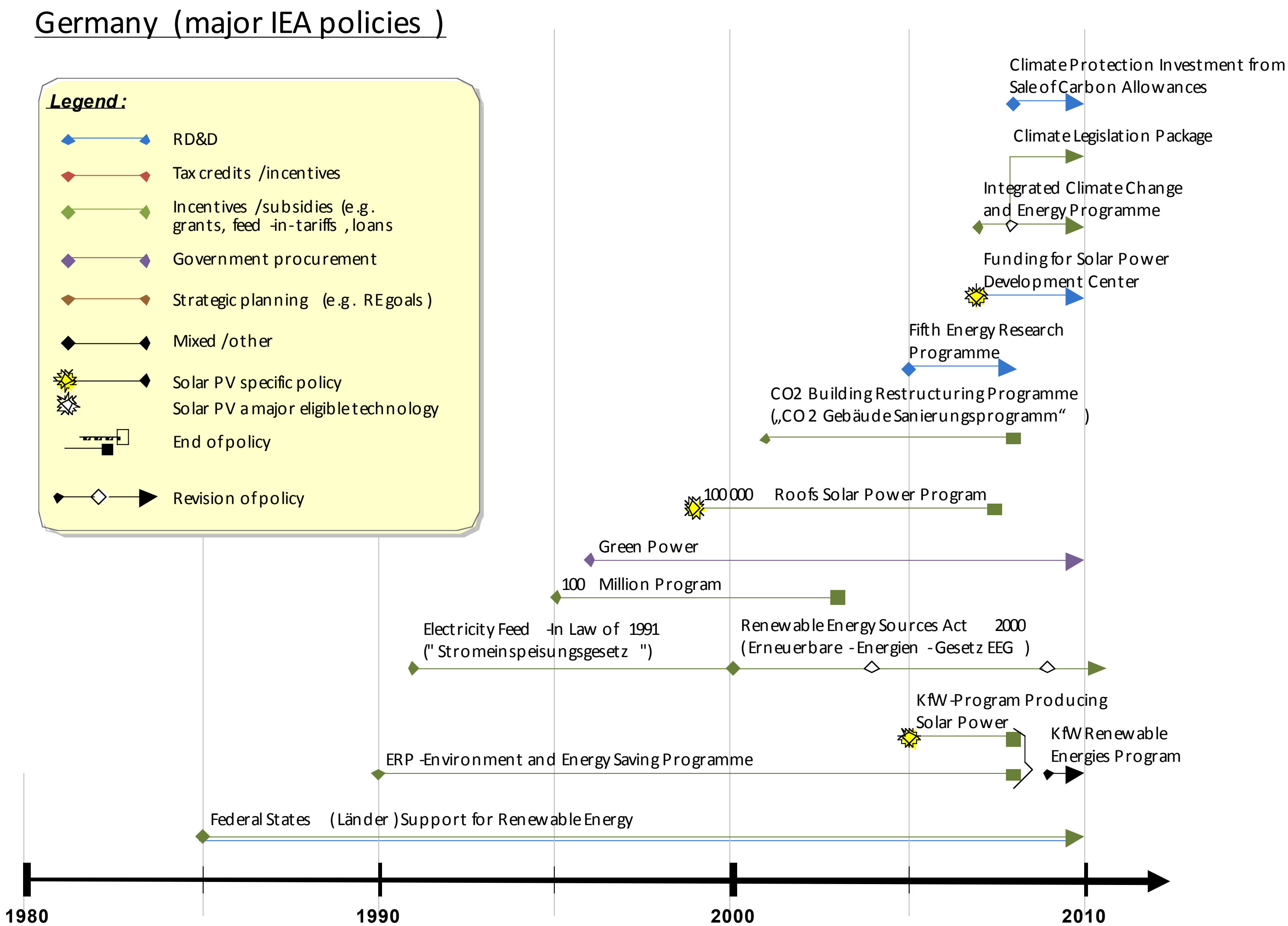

Figure 3: Policy milestones in Germany

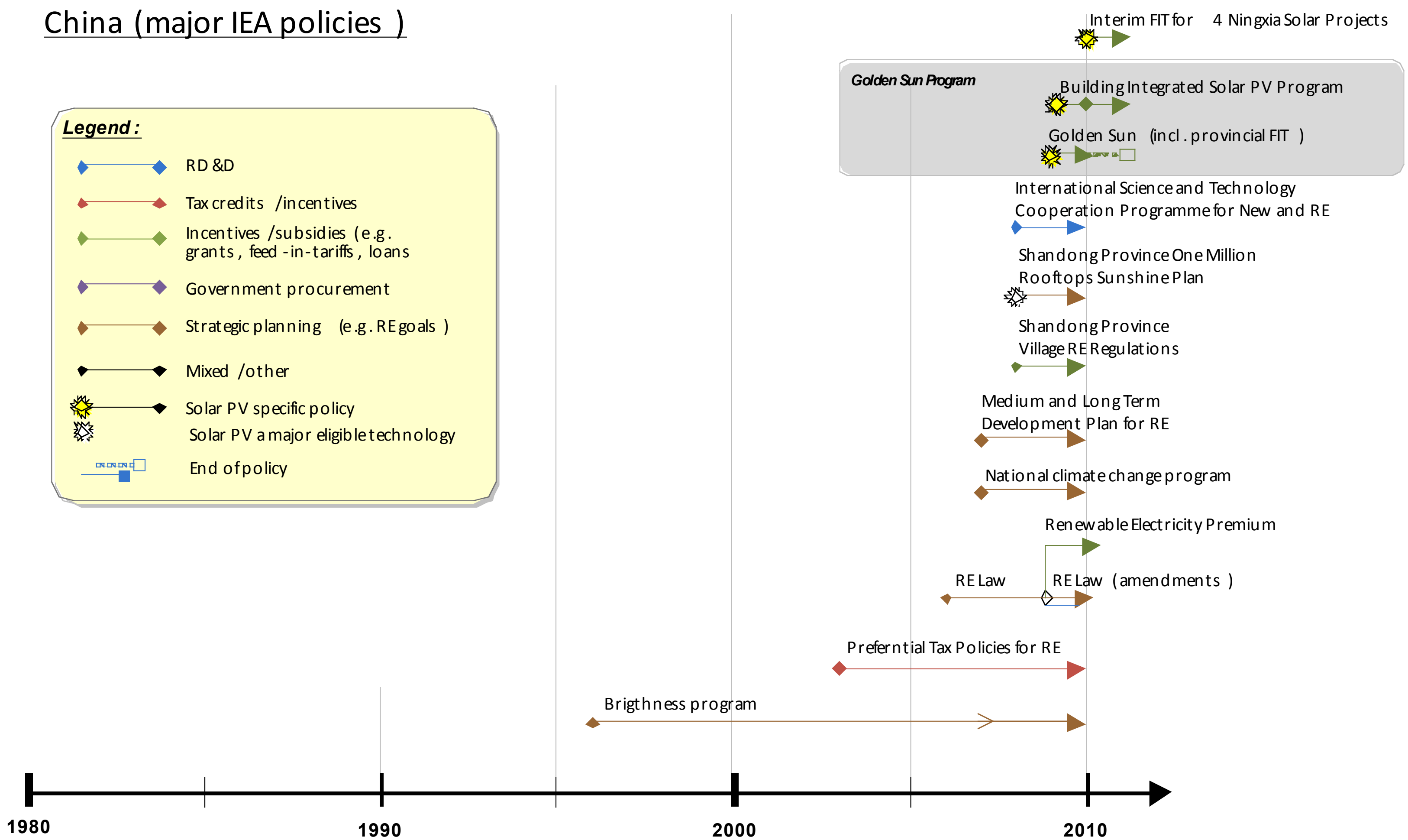

Figure 4: Policy milestones in China