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# The cost-effectiveness of solar PV deployment subsidies.

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**Abstract:**

This study attempts to calculate the financial value of the impacts of feed-in tariffs in Germany and Spain, in four key areas: the reduction of carbon emissions; the creation of jobs; improvements to energy security; and the stimulation of cost-reductions in solar PV technology. It then calculates the cost of Germany and Spain's feed-in tariffs and compares this with the value of the impacts, asking: can it be shown that subsidies for solar PV in these countries are cost-effective? The study finds that useful estimates of financial value can only be calculated with respect to carbon emissions and job creation and that in each of these areas more robust methodologies would be desirable to improve these estimates. Nonetheless, it also finds that only under the most optimistic of assumptions does the financial value of these impacts begin to approach the expenditure on deployment of solar PV. In a world where economic policy is increasingly calling on governments to invest in greening their economies, the study concludes that countries and international policy institutions would do well to invest in developing robust methodologies for estimating the cost-effectiveness of renewable energy support schemes, in order to identify when, where and how these policies can most effectively harness scarce public resources.

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# Content

## List of Acronyms

| | |
|---|---|
| BoS | Balance of system |
| BMU | BundesministeriumsfürUmwelt, Naturschutz und Reaktorsicherheit [Germany's Federal Ministry for the Environment, Nature Conversation and Nuclear Safety] |
| EEG | Erneuerbare-Energien-Gesetz [Germany's Renewable Energy Sources Act] |
| EPBT | Energy payback time |
| ETS | Emissions trading system |
| FIT | Feed-in tariff |
| GHG | Greenhouse gas |
| GO | Guarantee of origin |
| GW | Gigawatt |
| IEA | International Energy Agency |
| IMF | International Monetary Fund |
| kWh | Kilowatt hour |
| MW | Megawatt |
| PV | Photovoltaic |
| R&D | Research and development |
| RETs | Renewable energy technologies |
| WTO | World Trade Organization |

## 1 Introduction

Over the last decade several countries have introduced subsidies with the aim of increasing the deployment of solar PV. These policies have incentivised many other countries to develop similar schemes to attempt to replicate some of the perceived positive outcomes. The policies have also attracted many critics, who question whether deployment subsidies are the best way to achieve governments' policy objectives and whether the costs can be justified. This paper analyses the cost-effectiveness of deployment subsidies for solar PV in two European countries, Spain and Germany, and considers what lessons other countries might draw from their experience.

## 2 Methodology

In this study, cost-effectiveness is assessed in two steps: first, estimating the effectiveness of the subsidies, which is to say, the extent to which they have brought about their intended outputs and outcomes, as stated or implied in policy objectives; and second, estimating the costs of the policies, and asking if the identified outputs and outcomes can be thought of as having been achieved at a 'reasonable cost'. The common objectives that governments set out to achieve through subsidies for renewable energy deployment, broken down into intended outputs and outcomes, are listed in Table 1 below.

**Table 1: Deployment subsidies for RETs (Renewable Energy Technologies): a summary of policy objectives, intended outputs and intended outcomes**

| Policy objectives | Intended outputs | Intended outcomes |
|---|---|---|
| Environmental goals:<br>• mitigation of climate change<br>• reduction of local pollution | Increased deployment of renewable energy | Renewable energy generation will offset carbon-intensive energy sources, resulting in less $CO_2$ emissions and local pollution. |
| Economic and social goals:<br>• industry creation<br>• job creation<br>• regional development | | Increasing deployment of renewable energy technologies can:<br>• foster national industries, creating jobs in manufacture, installation and maintenance, and allowing for the export of RETs and related services<br>• allow for the export of renewable energy to countries that are not generating enough renewable energy to meet their own targets<br>By influencing the location of investments, this economic wealth can be targeted at the development of specific regions. |
| Energy security goals:<br>• increased energy security | | Increasing the share of renewable energy will increase the diversity of the energy supply mix, making a country less reliant on other sources of supply, notably imported fossil fuels. |

| | | |
|---|---|---|
| Development of RETs:<br>• cost reductions | | According to 'learning by doing' models, as a rough rule of thumb costs will be reduced by a fixed amount every time the installed capacity of a renewable energy technology doubles. Market support for RETs will also stimulate private investment in research and development (R&D). These cost reductions will, in turn, lead to increased deployment of RETs, contributing to all three of the outcomes listed above. |

In addition to the general objectives listed in the table above, most countries state a specific target for the increased deployment of various RETs, and sometimes state targets for specific outcomes too – for example, absolute or relative amounts of solar PV deployed by a certain date, reductions in $CO_2$emissions or increases in jobs. In this analysis, specific targets were not considered. Effectiveness was identified as the impacts of the policy with respect to each of these general objectives.

The analysis attempts to assess cost-effectiveness by estimating the economic value of the outcomes that have been achieved and comparing this with the financial burden of the subsidies.

# 3 Estimating the effectiveness of deployment subsidies for solar PV

## 3.1 Environmental goals

Currently available PV technology can reduce carbon emissions by offsetting more carbon-intensive energy sources. The Energy Payback Time (EPBT)[1]is by no means short, with estimates ranging from 1-5 years(Masakazu Ito K. K., 2010)(Vasilis M. Fthenakis, 2008) depending on the expected environmental conditions, the technology deployed and calculation methodology used, but this is significantly less than the lifetime of the technology, with silicon PV modules typically being marketed with warranties of 20-25 years. Calculating the impact of increased deployment on carbon reductions and local air pollution is dependent on a number of factors: the source of energy offset by the solar PV, the source and amount of energy consumed during manufacture and the performance characteristics of the installation. Solar PV is most likely to replace electricity generation that is readily deployable to balance fluctuations in demand, usually gas or coal-based technologies.

Studies have estimated that the rate of life-cycle $CO_2$-equivalent emissions for electricity generated from PV is between 30-45g $CO_{2e}$/kWh for silicon-based modules and as low as 24g $CO_{2e}$/kWh for CdTe cells(Vasilis M. Fthenakis, 2008).As gas is generally the most easily dispatchable form of fossil electricity generation, turned on and off at short notice in response to fluctuations in demand, and coal-based generation is the most common 'new build' technology to be displaced, it is likely that in most countries additional generation from solar PV would offset one or other of these sources, at least while renewables make up a relatively small percentage of the overall electricity mix. IEA data for 2008reports that the $CO_2$ emissions from electricity generated from gas are 278 g $CO0_2$/ kWh and 345 g $CO_2$/ kWh for

[1]Where EBPT is the time it takes for the PV module to produce the amount of energy used in its manufacture.

Germany and Spain, respectively; and the emissions from electricity generated by coal are 827g $CO_2$/ kWh and 901 g $CO_2$/ kWh (IEA, 2010). This indicates that on average solar PV offsetting conventional generation can reduce greenhouse gas (GHG)emissions by around 85-95%. Therefore, although electricity from solar PV is not carbon-free, the savings are considerable.

Assessing the value of emissions offset is difficult as no consensus exists over the 'right' price for carbon. Prices also change with time, as cheaper mitigation options are exhausted. This study looked at existing and projected prices for emissions trading schemes in order to assign a financial value to the carbon offset. As a lower band, the EU Emission Trading Scheme (ETS) price of carbon was used. This has never reached higher than €35 per tonne and has generally remained below €15 per tonne since the scheme was launched (Environmental Audit Committee, 2010), at some points with a value of close to zero. For a medium and high band, values were derived from integrated assessment models of the emissions cost needed to limit $CO_2$levels to 550ppm, from sources whose estimates ranged from US$ 135–380 (€105−295) by 2060(IMF, 2008). For the purposes of analysis, low, medium and high values of €15, 50 and 200 were assigned to indicate the range of possible carbon prices.

In the context of Germany and Spain, it should be noted that the EU Emissions Trading System (ETS)co-exists alongside each country's national subsidies to promote renewable energy. This complicates matters, as the carbon price generated by the ETS is supposed to incentivize low-carbon innovation among the carbon-intensive actors who can do so most cost-effectively. It has been argued by Frondel (2008) that solar PV deployment subsidies in Europe cannot therefore claim any additional carbon savings − by reducing the total amount of carbon generated in the EU system, it will lower the carbon price by the value that would have been needed to reduce that carbon elsewhere, more efficiently. This logic would conclude that governments should limit their support for renewables to participation in the ETS. In practice, few governments seem prepared to do so. Indeed, where EU member states have accepted binding targets for renewable energy generation, they are actually prevented from limiting their involvement to the ETS.

While this argument cannot be dismissed, it should be noted that various counter-arguments have been made in response. It might be argued that complementary tools are appropriate because: the EU ETS has been widely criticised for failing to adequately incentivize low-carbon economic restructuring; that the electricity market in many countries is not competitive enough to respond efficiently to a market instrument like the ETS; that various externalities surround innovation, which, if uncorrected, might lead a carbon price to more effectively incentivize reductions in consumption than increased investments in the development and installation of new technologies; and finally that, from a political economy perspective, targeting emissions reductions in the energy sector could be the most pragmatic way to drive through serious low-carbon economic restructuring. Even if readers find some merit in such arguments, however, it should be borne in mind that subsidies are not therefore necessarily the appropriate tool to complement the EU's ETS.

Further exploration of these issues was not within the scope of this study, as the interactions between the EU ETS and renewable subsidies are dynamic and complex, especially with large proportions of renewable energy in the electricity mix. We have instead adopted a conservative approach, and chosen to estimate of the value of carbon saved in Germany and Spain assuming a best-case-scenario of no leakage elsewhere in the EU ETS. Readers are advised, however, to interpret these numbers in light of the above concerns. Those wishing to read further about interactions between renewable energy subsidies and emissions trading schemes can find additional analysis in Gonzalez (2007).

Other assumptions involved in the estimate included a 30-year project lifetime and a $CO_2$ saving of 90% of the generation displaced. The average $CO_2$ emissions offset were estimated using the IEA data on coal and gas described above, and 2009 emissions factors were used for all emissions after that date. Sensitivities were included for project lifetime (20,30 or 40 years), the fuel displaced (coal or gas) and the price of carbon.

**Table 2: Value of carbon offset over project life**

| | | Value of carbon saved (EUR/kWh) | | | |
|---|---|---|---|---|---|
| | | **Germany** | | **Spain** | |
| | Total power generated (GWh) | 270,155 - 135,077 | | 252,209 - 126,105 | |
| **Scenarios** | **Carbon price (EUR/tonne)** | **High** | **Low** | **High** | **Low** |
| **Low** | 15 | 0.01 | 0.00 | 0.02 | 0.00 |
| **Med** | 50 | 0.05 | 0.01 | 0.05 | 0.01 |
| **High** | 200 | 0.20 | 0.03 | 0.22 | 0.04 |

The local air pollution objective identified in the list of common objectives in the methodology was not considered in this study, as neither Germany nor Spain has explicitly targeted this policy, and neither country's tariffs were varied according to any air quality indicator.

## 3.2 Economic and social goals

An objective of subsidies for the deployment of solar PV is often stated to be encouraging sustainable economic growth, sometimes referred to in the context of calls for a 'green economy'. The rationale is that economic activity surrounding deployment and generation could provide economic benefits in several ways, though each will have more or less relevance depending on the country in question. First, through developing a globally competitive solar PV manufacturing industry, including the production of wafers, cell, modules and Balance of System (BoS) items, countries can hope to capture a share of the global market in the supply of solar PV facilities, which may become highly significant, especially if costs reach grid parity. Secondly, where countries have particularly high levels of insolation, or neighbouring countries are willing to pay a premium for low-carbon electricity or the credits associated with it, countries could hope to export the energy generated by solar PV. In addition to the revenues generated from marketing and trading the outputs, this would also create economic activity in the installation and maintenance of the technologies themselves.

Estimating these economic benefits is complicated, however, and in order to be comprehensive it needs to take into account opportunity costs – could the same funds promote greater economic activity elsewhere? It is also necessary to take into account the longevity of economic gains. Some jobs that are created, such as those in installation, are short-term, and exist only as long as the new installations are being constructed. Uncertainty over future developments is an important issue in this respect. It is possible, for example, that many jobs will disappear when subsidies are eventually removed, as the 'infant industry' has not grown up and become competitive on a global scale, or because the projected technological cost reductions have not come to pass. On the other hand, should solar PV reach grid parity, it is difficult to estimate the potential economic gains that could realistically be assumed, depending both upon the size of the resulting global market and the share that could be captured by existing players.

Some caution should be urged with respect to the potential future promises of solar PV, and indeed the volatility that surround the economic impact of subsidy policies. In the short-term, recent reductions in Spain's solar PV subsidy have made it clear the industry is still heavily reliant on feed-in tariffs, with reports of 15,000 jobs having been lost in the sector between summer 2008 and February 2009 (ASIF, 2009).Although no comparable fall in employment was observed at a global level, as demand for solar technology has continued to increase, current levels of production would be unsustainable without continued subsidies. If more countries were to reduce subsidy expenditure faster than costs are reduced, the demand shock would likely lead to job losses throughout the global industry. The German Federal Ministry for the Environment, Nature Conversation and Nuclear Safety (BMU) has recently announced cuts of 15% in its subsidy rates(BMU, 2011) and it is not yet clear what impact these reductions will have on installation rates and industry prospects as a whole.

### 3.2.1 Benefits from manufacturing

Germany has been relatively successful in developing a PV industry, currently representing around 15% of the global manufacturing of modules and approximately 19% of global polysilicon production. [(EC JRC, 2010), own calculations] The wisdom of this investment depends on whether costs fall sufficiently for the large-scale deployment of solar PV in other countries (or enough other countries follow Germany in providing substantial subsidies for the technology) and whether Germany can remain competitive once its domestic deployment falls as a share of global deployment.

There are several forces that affect competitiveness, including: labour costs, fiscal policy, strength in science and innovation and the availability of a suitable work force. Being established in the market can also play a significant role – countries wishing to follow the example of first movers may be at a disadvantage. As the PV industry becomes increasingly mature, new entrants are likely to see the potential benefits reduced for an equivalent cost.

Policy makers are also likely to consider the effect of trade on any fledgling renewable industries they are trying to foster. Local interests may favour protectionist measures, such as import tariffs or local content requirements, to generate a short-term benefit for domestic producers. Such policies would be unlikely to provide benefits in the long term, as they would increase the cost of the deployment and undermine the competitiveness of the country's industry. In practice, the extent to which such measures are even possible is constrained by World Trade Organisation

(WTO)law,[2] and in the EU by EU competition law. So far the approach taken by Germany and Spain has been to keep tariffs low, despite industry pressure (Jacob Funk Kirkegaard, 2010).

With low trade tariffs and high subsidies concentrated in a few markets, it is unavoidable and from a global public good perspective, quite desirable) that the subsidies provided by one country will be distributed amongst all competitive suppliers, not exclusively those based within their own borders. This is borne out by the fact that Germany, despite funding the deployment of more than half of current global PV capacity, has recently lost ground to China in terms of global market share in PV manufacture. China's market share has increased to over 30% in 2009 (EC JRC, 2010) up from a very low base in 2005. This fact is uncomfortable for politicians. The stated objective of creating domestic jobs is faced with the realities of a global industry. Ultimately, deployment subsidies that do not discriminate between domestic and foreign players will provide only an indirect incentive to manufacture in the domestic economy, due to factors such as lower transport costs, ease of doing business and direct access to customers.

The low tariffs in Germany and Spain suggest that although the high proportion of imports will have led to fewer domestic jobs being created, and despite the fact that the demand for solar PV may be dependent on subsidies, the jobs that do exist are more likely to be globally competitive.

Compared to the levels of solar PV manufacturing in other European countries, it seems that Germany's subsidies have helped stimulate a larger domestic solar PV manufacturing industry than would otherwise be the case, securing a sizeable share of the world market. By contrast, Spain does not manufacture a significant amount of the global supply of solar PV, suggesting that its policy has been less effective in this respect. Although it was outside of the scope of this study to explore the reasons for this disparity, one explanation could be the role of innovation as a key driver of competitiveness. In a survey of patent applications for renewable energy technologies (ICTSD, 2010), Germany was ranked as 3rdand Spain 17th.Alternatively, it is possible that market players with a 'first mover' advantage are better placed to be ahead of the curve in innovation and manufacturing. Both Japan and the USA, which like Germany have been pioneers in supporting this technology, were also highly placed in the survey, whereas Spain's solar PV subsidies only began to deliver significant deployment after Royal Decree 436 was issued in 2004.

### 3.2.2 Economic benefits: jobs created

For the purposes of this study, job creation was chosen as an indicator for the economic benefits of solar PV subsidies. To estimate the number of jobs created in Germany and Spain, an indicator for the employment intensity of each activity was used(US Department of Energy, 2008; Friedman, 2009). The activities were divided in to those that could be performed globally, such as module manufacture, and those that are performed locally such as installation. This analysis provided an estimate for

[2]Note the consultations that took place on this issue in 2010 and 2011 between the U.S. and China (http://assets.usw.org/releases/misc/section-301.pdf) and Japan and Canada. Although the U.S. and China have reportedly reached an amicable resolution, is not currently clear how the consultation between Japan and Canada will develop, nor whether cases of a similar nature will be taken to the WTO in the future.

the number of jobs involved in deployment (5.8 - 20.8 per MW) and manufacture (approximately 16 per MW).

The global activities can be combined with global installation levels and estimates for the global market share of each country (EC JRC, 2010)(own calculations). The duration of jobs is given either as an activity that takes place in a single year (installation jobs) or one that is tied to the expected life of the project (maintenance jobs). This has been used to provide an estimate for the total employment on a common basis in the years 2008, 2009 and cumulatively over the life of all projects installed between the years 2000-2009.

**Table 3: Employment estimates (EC JRC, 2010; Friedman, 2009) (Own calculations)**

| | Employment estimate (Job years) | | |
|---|---|---|---|
| | **2008** | **2009** | **Cumulative** |
| **Spain** | 24,877 | 3,590 | 94,561 |
| **Germany** | 40,145 | 62,518 | 226,393 |

Industry and government estimates for Germany in 2009 seem to fall in a similar range: 68,000 in 2009 (BSW-Solar, 2010) and 64,600 in 2009(BMU, 2010). An industry estimate of 15,000 jobs was reported in early 2009 (ASIF, 2009) in Spain, also of the order estimated here.

It should be noted, however, that there are considerable complexities with determining the impact of deployment subsidies on national economies and that these numbers are extremely conservative in favour of solar PV.

The root of this bias lies in the fact that although it is relatively simple to estimate the number of jobs created in the solar PV industry, it is much more difficult to determine the *net* impacts that feed-in tariffs will have on employment across an economy. There are two main impacts to consider.

First, the public resources being directed towards solar PV technology will no longer be spent elsewhere in the economy, with the result that we would expect economic activity elsewhere to diminish. The true ‘gain’ of expenditure on solar PV should strictly be calculated as the jobs that are created, minus the jobs that have been lost due to this redirection of resources. This study failed to identify any robust methodology for conducting such an analysis, short of economic modelling.

Second, most feed-in tariff schemes are designed such that the increased cost of purchasing renewable energy is paid for by charging consumers higher rates for their electricity consumption. In Germany, for example, the BMU reports that between 2000–2009 the average electricity bill per household per month rose from €46.67 to €65.97. Of this, the cost incurred by the Renewable Energy Resources Act (the EEG, which includes a number of RETs, and not just solar PV) increased from €0.58 to €3.10(BMU, 2009). Although these premiums appear small, at an economy-wide level they can be expected to have impacts on international competitiveness for electricity-intensive industries.

Analysis from other studies indicates that these impacts should not be under-estimated. According to the business-as-usual scenario in a modelling exercise conducted for the European Commission, the net employment gain for Germany with respect to *all* renewable energy technologies – not just solar PV – was estimated at 25,000–33,000 jobs by 2020, with the higher range representing an 'optimistic exports' scenario. GDP was projected to grow by 0.10–0.14% compared to a no-policy scenario. Another model in the same project estimated that there would be a net *loss* of employment in Germany of around 10,000 jobs, although GDP gains were still projected at 0.1%. In Spain, the models projected, respectively, that there would be an additional 6,000–11,000 jobs by 2020,with GDP growth of 0.12%–0.16%; or an additional 120,000 jobs, with a little over 0.25% additional GDP(Ragwitz, et al., 2009).

### 3.2.3 Benefits from low-carbon electricity generation

Low carbon electricity generation can also create economic activity. A country able to generate renewable energy more cheaply than its competitors could become an exporter, not of technology, but of energy or credits representing renewable energy. In the case of Spain, with the best solar resources in Europe and significantly lower deployment costs compared to Germany, this approach could be an alternative way to generate economic growth.

Mechanisms exist for the cross border trading of renewable energy credits (Guarantees of Origin) and the rules governing their eligibility are still developing. To date, all EU member states have been required to establish and maintain a GO scheme, but as of yet there has been no major trade in renewable energy from either Germany or Spain, neither or which has yet achieved its own domestic targets under the EU's Renewable Directive, which is likely to be a prerequisite for international trade.

The economic value of electricity generated, however, defined as the market price of electricity, has been taken into account as one of the 'benefits' of the renewable energy subsidies. There are complexities in this area, as technically the EU ETS ensures that these market power prices already reflect the costs of carbon emissions – meaning that when the value of the carbon savings is also considered, there will be an error due to double counting.

In order to get an approximate indication of the potential size of this effect, the value of the carbon emission savings already calculated was compared to the value of the wholesale electricity price in Germany (see Table 4 below). This indicates that a significant proportion of the power price may be made up of internalised carbon costs. While this illustrative example does not fully capture the complexities of the interaction between carbon prices and electricity prices, it does indicate that when projected carbon prices are added to wholesale power prices there may be a significant element of double counting, though noting that EU ETS prices may not fully reflect what the 'right' price for carbon should be.

For the purposes of this report, the impact that the carbon price has had on electricity prices is noted but due to the modelling complexities it was not attempted to separate out the carbon component of the power price. Readers should be aware that there is likely to be an element of double counting between the values calculated for power and carbon prices.

**Table 4: Estimated contribution of carbon emissions cost to whole sale electrical cost for Germany in 2009**

| | | **Value of carbon saved (% of wholesale price)** | |
|---|---|---|---|
| | Wholesale electricity price EEX 2009 (EUR/kWh) | 0.03885 | |
| **Scenarios** | **Carbon price (EUR/tonne)** | **High** | **Low** |
| **Low** | 5 | 10% | 3% |
| **High** | 15 | 29% | 10% |

## 3.3 Energy security

Increased energy security is commonly cited as another benefit of promoting renewable energy technologies: if the overall share of imported energy is reduced, the country will become less sensitive to threats to supply such as price volatility, political instability in energy-exporting countries, competition for limited resources, industrial action, collusion and market manipulation and the disruption of infrastructure due to adverse weather, natural disasters or terrorism.

In 2009, however, the proportion of energy generated by solar PV was approximately 1% and 2% of total electricity generation in Germany and Spain respectively (IEA, 2010). Although not insignificant, at this level of deployment the effects on energy security are small, as both countries are still heavily reliant on global energy markets.

In addition, the reliability of solar PV is also a factor that must be taken into account in considering its role in increasing energy security. Solar resources are dependent on weather conditions and with current technologies there are limited storage options for electricity, meaning that electricity generated from solar PV can only be dispatched when it is available and not necessarily when it is most needed. The technology is therefore best suited when combined with other technologies that can level out its variability or be turned on or off at short notice to balance supply and demand.

Absent a full analysis of Germany and Spain's energy security dynamics, and the bigger picture of deployment subsidies for all renewables – both of which are outside the scope of this report – the most that can be said is that the proportion of electricity generated by solar PV electricity in both countries suggests a positive effect on energy security, but that – in and of itself – spending on solar PV is unlikely to have greatly affected the situation of either.

## 3.4 Development of RETs

Reducing costs over time is essential for the long term success of solar PV and a key objective of support mechanisms –lower costs will allow for increased deployment at any given level of spending, with attendant impacts on the cost-effectiveness of any environmental, economic and energy security benefits that are achieved. Should solar

PV prices reach grid parity, a large market will develop for the technology and subsidies would no longer be necessary.

Part of the rationale behind deployment subsidies is that the expansion of the solar PV market and increased levels of production will provide opportunities for 'learning by doing', as well as promoting R&D among private investors. It is hoped that eventually this will lead to grid parity, followed by further feedback mechanisms leading to even lower technology costs –'run-away grid parity'.

It is difficult, however, to determine to what extent past cost reductions have been driven by deployment. According to one analysis of solar PV cost reductions, costs are estimated to have fallen by more than 90% over the last 30 years, with 43% of cost reductions being correlated with plant size, 30% with efficiency and 12% with the cost of silicon (Nemet, 2006). Although plant size is strongly related to production levels, increased efficiency could be achieved both through increased production levels and the efforts of research and development.

Estimating future cost reductions is similarly difficult. The relationship between increased deployment and costs is traditionally modelled by learning curves, which predict as a rough rule of thumb that costs fall at a constant rate with each doubling of cumulative production volumes during a 'linear leaning' phase of a technology's development, based on the correlation between past costs and production volumes. In some studies, linear learning rates used to predict cost reductions over a period of many years. Some also try to take into account the impacts of research and development – 'learning by searching'. While these models are sometimes used to justify high-cost deployment subsidies on the basis of future cost reductions, this study would caution against this approach for a number of reasons.

First, there is a high degree of uncertainty inherent in any such calculations. Learning rates are calculated as a constant with respect to cumulative production volumes, so small changes in starting conditions can have a large impact on the outputs. For example, two large studies of solar PV learning curves found learning rates of 17% and 26% (Strategies-Unlimited, 2003),(Maycock, 2002). If extrapolated, these learning factors predict that solar PV will break through the $1 per watt barrier at an annual level of production between 10 to 100GW (own calculations). The breadth of this range illustrates how sensitive learning-factor calculations can be, and by consequence, the significant uncertainty surrounding estimates of cost reductions that can be achieved by deployment subsidies.

Second, the linear phase of technological development does not last forever. Caution should be exercised when applying learning rates far into the future, as constant learning rates eventually give way to a period with a declining learning rate, known as 'maturity', and finally a learning rate close to or equal to zero, 'senescence' (Ferioli, Schoots, & van der Zwaan, 2009). In spite of this, models frequently assume that a constant learning rate can be sustained indefinitely, risking the inclusion of considerable error. Alternative approaches to estimating future cost reductions including component learning hypothesis(Ferioli, Schoots, & van der Zwaan, 2009) or technical evaluations of opportunities for cost reduction(Wim C. Sinke, 2009) but even where these corroborate estimated potential cost reductions, they do not necessarily establish the same causal link between deployment and cost reductions.

Third, on a pragmatic level, it is also the case that many cautionary tales exist about industries that have justified subsidies on the basis of long-term savings that ultimately never materialize. For example, according to Koplow (2011), the nuclear power industry in the United States has been claiming since at least as far back as 1954 that it will soon be economically competitive, yet continues to receive substantial subsidies.

Given the difficulty of determining the cause of cost reductions and the uncertainty of future projections, this study considered it unfeasible to assess the extent to which deployment subsidies had incentivized technology development. Broadly, it seems clear that the costs of PV are likely to reduce in two main ways: 'learning by doing' in production and research and development into increasing cell efficiency.

It should be noted that this uncertainty also has implications for cost-effectiveness: it is intuitive that spending will be more or less efficient in stimulating technological innovation depending upon how funds are shared between deployment and research. Although it is insufficient for drawing any confident conclusions on this matter, a useful indicator may be the proportion of total funds dedicated to solar PV that are spent on deployment as compared to R&D.In Germany, for example, the Federal Ministry for the Environment, Nature Conversation and Nuclear Safety (BMU) had a budget of €32.1 million EUR in 2007(Global Green , 2009), and during the same year the total spending on solar PV was around €1.5 billion; and the total spending commitment made to newly installed capacity in 2007 was approximately €8 billion (own calculations). Although the measure could be improved by a more comprehensive survey of potential research and development funding, this approximate picture corresponds with other sources. The *World Energy Outlook 2010*, for example, identifies over US$7 billion of government spending on solar PV deployment subsidies in 2009, versus only US$3 billion of public and private spending on research and development (IEA, 2010).

It should be cautioned, however, that this indicator is descriptive only. In order to recommend a relative share of spending in different areas, it would be necessary to determine the cost-effectiveness of subsidising research and the extent to which deployment subsidies can be credited with stimulating private R&D. A more nuanced definition of research and development would also be required to identify exactly where in the innovation cycle and how funds were being most usefully targeted.

## 4 Effectiveness Summary

To assess whether the subsidies have had their desired effects, each of the goals listed earlier is now presented alongside estimates of the actual outcomes of the policies (see Table 5). This summary indicates that both countries have achieved the desired *output* of the policies, in terms of increasing the levels of the technology being deployed, but that this deployment may not have always led to positive results under some of the outcome indicators.

### Table 5: Summary table of effectiveness objectives, outputs and outcomes

<table>
<tr><th>Policy objectives</th><th>Outputs</th><th>Intended outcomes</th><th>Estimates of actual outcomes</th></tr>
<tr><td>Environmental goals:<br>• mitigation of climate change<br>• reduction of local pollution</td><td rowspan="4">Increased deployment of renewable energy (installed capacity):<br><br>Germany – from 76MW in 2000 to 9,845MW in 2009<br><br>Spain – from 2MWin 2000 to 3,523MW in 2009</td><td>Where increased renewable energy generation is greater than growth in demand, it will offset carbon-intensive energy sources, resulting in less $CO_2$ emissions and local pollution</td><td>Carbon savings:[1]<br>Germany – 50.2−150*Mtonnes$CO_2$<br>Spain –58.7−140.77*Mtonnes $CO_2$</td></tr>
<tr><td>Economic and social goals:<br>• industry creation<br>• job creation<br>• regional development</td><td>Increasing deployment of renewable energy technologies can:<br>• foster national industries, creating jobs in manufacture, installation and maintenance, and allowing for the export of RETs and related services<br>• allow for the export of renewable energy to countries that are not generating enough renewable energy to meet their own targets<br><br>By influencing the location of investments, this economic wealth can be targeted at the development of specific regions.</td><td>Share of global module production (2009):<br>Germany − 14.3%<br>Spain −<1%<br><br>Share of global polysilicon production (2009)<br>Germany − 19%<br>Spain −<1%<br><br>Cumulative 'job years':<br>Germany – 230,000<br>Spain – 95,000<br><br>Patent activity ranking<br>Germany – 3rd<br>Spain – 17th</td></tr>
<tr><td>Energy security goals:<br>• increased energy security</td><td>Increasing the share of renewable energy will increase the diversity of the energy supply mix, making a country less reliant on any one source of supply.</td><td>Proportion of electricity from PV:<br>Germany – 1%<br>Spain – 2%</td></tr>
<tr><td>Development of RETs:<br>• cost reductions</td><td>According to 'learning by doing' models, costs will be reduced by a fixed amount every time the installed capacity of a renewable energy technology doubles. Market support for RETs will also stimulate private investment in R&D. These cost reductions will, in turn, lead to increased deployment of RETs, contributing to all three of the outcomes listed above.</td><td>No appropriate indicators identified</td></tr>
<tr><td colspan="4">[1] Range dependent on fuel type being offset: and the lower end, gas, and at the higher end, coal.</td></tr>
</table>

Overall, the indicators suggest that the subsidy programmes − the primary cause of the increased deployment of solar PV − have contributed to meeting their intended policy objectives.

In comparing Germany and Spain, as can readily be expected, the subsidies appear to have had comparable impacts in terms of environmental and energy security goals. The differences that can be observed in energy generated and carbon saved can be explained by differences in solar resource, the overall subsidy expenditure and the effectiveness of the scheme design.

The key differences are found in the outputs relating to economic and social goals. In terms of global market share and jobs created, it is clear that Spain has not succeeded in stimulating as successful a manufacturing industry as Germany. In terms of research and development, Germany is rated as having a greater number of patents and therefore likely to be more successful as international hub for research and development. Together, these facts suggest that either (i) the German subsidy scheme has been more effective at supporting the domestic PV industry, or (ii) neither subsidy scheme is more effective at incentivising domestic manufacture and other factors have led to Germany's superior performance.
Having established that the policy does appear to have been at least partially effective in achieving its intended outcomes, it is necessary to ask if the policy can be considered cost-effective– were its objectives achieved at a 'reasonable cost'?

## 5 Cost effectiveness

An assessment of the cost-effectiveness of these subsidies must first begin by estimating their costs. Then, two lenses of analysis can be applied. First, were the policies cost-effective in an 'absolute' sense – in other words, would other policy tools be more effective at the same cost? Second, were the policies cost-effective in a 'relative' sense – was one subsidy scheme designed in a way that made it more efficient than the other?

### 5.1 Calculating scheme costs

The total cost of the subsidies was estimated by identifying the annual increase in generation in each country for each year between 2000 and 2009. Each cohort of installations was then assumed to receive the feed-in tariff (FIT) rate available in the year the generation was added and to receive the FIT for the length of time specified under the scheme conditions. The effective FIT rate was determined by creating a weighting for each available category of FIT and combining this into a single tariff. The generation and therefore the cost of the scheme was assumed to be constant throughout the life of the subsidy. Data on solar PV generation was sourced from the BMU (2010), the IEA (2010) and the author's own calculations. Data for the weighting of the tariff bands came from Renewables Insight (RENI, 2010) and Segaar (2010). Data on feed in tariffs was sourced from Porta (2009) and BSW Solar (2010).

The 'total commitment' estimated is the sum of all subsidies due to be paid to capacity installed between 2000−2009, over the entire lifetime of the subsidy policy. In Germany, each solar PV installation was guaranteed to receive payments for 20 years; in Spain, for 25 years.

**Figure 1: Estimated subsidy expenditure by year for Germany (left) and Spain (right), adjusted for inflation**

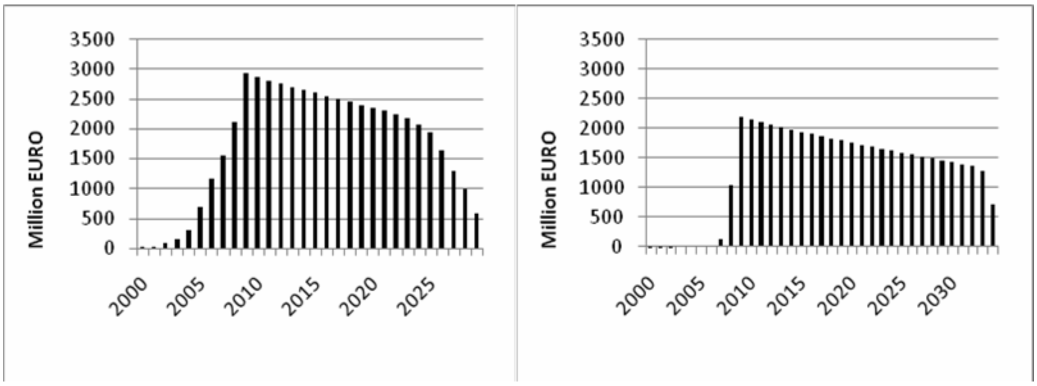



**Table 6: Key indicators on the lifetime financial cost of deployment subsidies guaranteed to solar PV installations that came online in the period 2000-2009**

| | Spain | Germany |
|---|---|---|
| Total commitment 2000−2009 (€ billion)(adjusted for inflation) | 45.5 | 52.9 |
| Total TWh of electricity generated | 152,575 | 130,720 |
| Total cost per kWh (€/kWh)(adjusted for inflation) | 0.30 | 0.40 |
| Yearly average solar yield (kWh/kWp/yr) (data from PVGIS) | 1,300 | 950 |

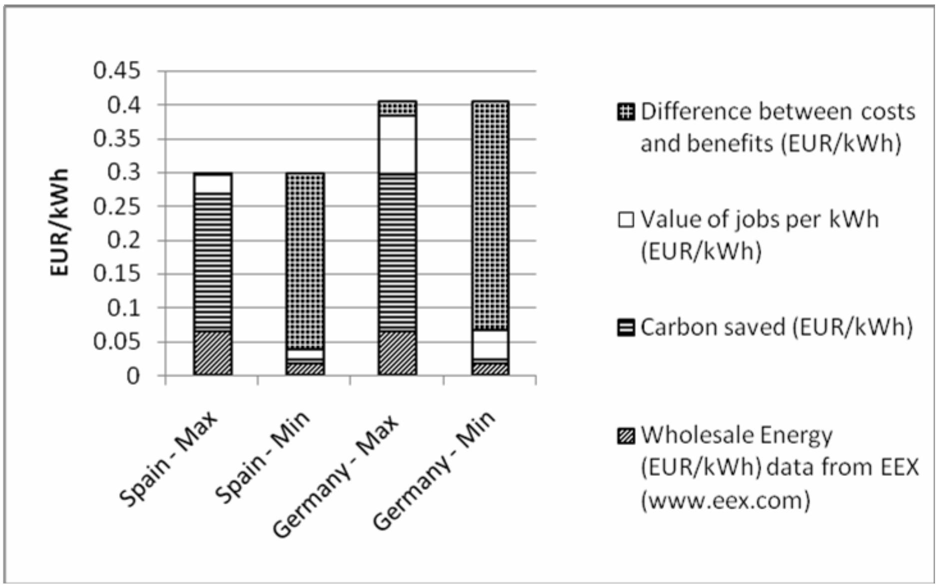
**Source:** author's own calculations, from a range of sources (adjusted for inflation). See Annex for detail.

### 5.2 Absolute cost-effectiveness

Studies looking at the cost-effectiveness of solar PV have often focused on one particular outcome being targeted by the policy(Manuel Frondel, 2008; Gabriel Calzada Álvarez, 2009).This approach can result in the entire cost of the policy being compared to the value of a single benefit. The approach taken by this analysis is to estimate a financial value for as many of the outputs as possible and to compare this to the absolute cost of the scheme. Estimates were made for the financial value of energy generated, carbon emissions offset and jobs created over the life of projects that were committed to in the period analysed (2000-2009). This data is shown in comparison to the subsidy cost in figure 2.

In order to reflect the considerable uncertainty regarding the financial value of the benefits conferred by subsidies for solar PV, sensitivity analysis was used to derive the minimum and maximum values of benefits for each country. The extreme of either end is unlikely – the true value almost certainly rests somewhere between the two.

**Figure 2: Graph indicating cost and value of PV subsidies over project lifetime for projects installed between 2000 – 2009**




The value of offset carbon emissions is a particularly important variable in determining the ultimate cost-effectiveness of these policies. If the value of offset carbon is believed to be in the order of €200 per tonne, then the benefits of solar PV subsidies in Germany and Spain may start to become comparable with the financial costs of the subsidy expenditure, if we take into account the value of other benefits, such as economic impacts. At a carbon value of €296−350 per tonne (own calculations),and assuming the displacement of coal generation, the value of the carbon offset would justify the current subsidy expenditure without taking into account impacts against any other objectives. At both levels of spending, there are many alternative investments that could be used to reduce carbon at lower costs (Bloomberg New Energy Finance, 2010). In addition, it should be noted – as described more fully in the analysis of effectiveness earlier – that when deployment subsidies are combined with an emissions trading scheme, there is the potential for none of these reductions to be additional: by reducing the amount of carbon in the system, the carbon price will lower, and the ETS will incentivize fewer carbon reductions that could have taken place more efficiently elsewhere.

The value of the jobs created by solar subsidies is also an important variable. As with carbon prices, the range between the minimum and maximum estimate is considerable, dependent on the nature and duration of the jobs created. Differences in the type of technology deployed − in particular whether systems are grouped in distributed or large centralised arrays–also greatly affects the estimates. Other uncertainties include the relative economic value of different jobs and the lack of distinction between a company's country of origin and location of manufacturing facilities.

The two missing elements in the graph are the financial values of the benefits conferred by increased energy security and technological innovation. It is not possible to estimate a financial value for energy security benefits because, as identified earlier, it is beyond the scope of this report to determine the impacts of solar PV subsidies on energy security, except for fairly broad generalisations. Attempts to estimate the scale of these financial benefits may do more harm than good unless it is based on a comprehensive understanding of how solar PV fits into the larger picture of energy supply in each country, and even then is perhaps best restricted to a complementary qualitative analysis.

By contrast, it is clear that if it were it possible to estimate the financial value of technological cost reductions, this could potentially bridge the gap between the costs and benefits in each country. The effect would be larger for countries that are well-placed to benefit economically from solar PV expansion, either due to competitiveness in manufacturing of richness in solar resources.

Taken together, the analysis indicates that even within the minimum and maximum sensitivities explored, the financial cost of the subsidies committed by Germany and Spain between 2000 and 2009 is likely to outweigh the direct and readily quantifiable environmental and economic benefits. At current levels of penetration, it is not clear what value could be attributed to the energy security benefits in either country, especially because of the interrelatedness of solar PV with the larger energy supply dynamic. At large levels of penetration in electricity markets, it is likely that the value of energy security could provide large benefits, but these would need to be assessed in combination with the various additional costs required to deploy and manage large-scale penetration of solar PV in national grids. However, it seems reasonable to assume that, especially in the case of 'first movers', the picture might be different if it were possible to estimate the financial value of technological cost reductions brought about the subsidies – though emphasizing that it is by no means certain that this would tip the balance in the favour of deployment subsidies. Indeed, a question mark hangs over the cost-effectiveness of the share of funds dedicated to deployment subsidies as opposed to research and development.

### 5.3 Relative cost effectiveness

As shown in
Table 6,the cost of energy per kWh from the German subsidy was greater than in Spain. When adjusted for Spain's superior solar radiation, however, Germany's costs are significantly lower. This finding illustrates that the resource available will always affect the costs of generation, but it also suggests that some of the design characteristics of the German subsidy programme enabled it to operate at significantly lower costs than its Spanish equivalent. While it is not possible to conclusively establish which elements in the German scheme elements played the largest role in this success, it is useful to discuss the potential impact of some of the most likely candidates. This summary draws on Klein's (2008) detailed analysis of feed-in tariff design.

| | |
|---|---|
| **Stability** | Project prices fluctuate according to the risk that a project will fail due to legislative change. In Spain, the system was changed in 2004 (RD436), 2007(RD661) and again in 2008(RD1578), with each of these changes leading to rapidly increasing or declining installation rates. In Germany, the Renewable Energy Sources Act (EEG) was established in 2000 then amended in 2004 and remained with tariff levels as defined in 2004 until 2009. It is possible that this stability led to lower perceived risks and therefore lower costs. |

**Accuracy of tariff levels**

By using industry surveys and indicators, it is possible to determine with some accuracy the achievable rate of return for projects. Where installations have outstripped estimates, it is usually as the result of a project type that has not been accurately modelled. In 2008, a year of high installation rates for both countries, the tariffs for ground mounted arrays of 100kW or more was €0.355 in Germany and €0.4175 in Spain. What is striking about these numbers is that, despite both countries seeing high installations levels, and despite Spain having an approximately 36% higher solar resource, Spain were still providing a subsidy at a rate of approximately 17% higher than Germany and with a tariff lifetime 5 years longer (25 years). Due to the over-payment, Spanish PV installations soared and within a year a new Royal decree (RD1578) was introduced to reduce the installation levels. This incident indicates that the Spanish government of did not have a good understanding of the level of subsidy required to make PV viable in Spain. Consequentially, installations that were completed before the collapse of the scheme received, and continue to receive, excessive subsidies.

**Scheme complexity**

If a single tariff is used for all installations, the level chosen will either lead to a low take-up in some applications or an overpayment to others – for example, favouring large-scale solar PV plants over roof-mounted home units, each of which have different cost structures. To address this issue, both Spain and Germany adopted different tariffs for different types of solar PV installation. Until 2009, the Spanish tariffs were the same across all applications, rates were only determines by the rated output of installation. All installations below 100kW received the same rate. Germany additionally varied the rate depending on installation size and had a separate band for installations below 30kW.Rates were also varied according to whether the installation was building-integrated, building-mounted or ground-mounted. The additional complexity in the German system allowed the tariff levels to be tailored to the application and limited the risks of overpayment.

**Safety-valve mechanism**

To avoid runaway deployment, and therefore uncontrollable scheme costs, a safety valve mechanism can be used to reduce rates. This can either take the form of a regular review to set the digression rate based on scheme costs or with a predefined mechanism that links installed capacity to the tariff level. While this feature was not in place in either the German or Spanish system for most of the period, both countries have now introduced such a mechanism.

In some ways the stability of the subsidy scheme, the accuracy of the tariff levels and the scheme complexity are all related. To develop a scheme where the costs remain predictable and it is possible to maintain support for the policy, it is necessary to have a solid understanding of the solar PV industry to determine the subsidy levels required to make projects viable across the full range of sectors and applications. The evidence suggests that the German government were more successful in doing this.

## 6 Conclusions

This study estimates that the solar PV technology installed between 2000−2009 in Germany and Spain will commit each country to spending €52.9 billion and €45.5 billion, respectively, through their feed-in tariffs. This obligation reflects a success in stimulating solar PV deployment, which in 2009 represented 1% and 2% of electricity generation, again respectively.

In attempting to determine the cost-effectiveness of these policies, one of the most conspicuous conclusions of this study is methodological – that such analysis, if pursued earnestly, is extremely difficult to do comprehensively. Uncertainty looms large over every objective targeted by the policies: the appropriate price of carbon; the complexity of determining net economic impacts; the need for far-reaching analysis to estimate energy security gains; and the difficulty of determining the causal relationship between production rates and cost reductions. n some cases, the uncertainty leaves us with large ranges of possibility to consider. In others, the range is so large that attempting to quantify costs and benefits was considered unviable. Yet without at least reviewing all of these areas, any analysis will be incomplete.

The cost of the feed-in tariff from the 2000-2009 commitment was calculated at €0.30 per kWh electricity generated in Spain and €0.40 per kWh electricity generated in Germany. This study found that reasonable efforts could be made to evaluate environmental and economic impacts and their related financial benefits, although in each case identifying various areas where deeper analysis could be pursued. By these measures alone, it was only under the most optimistic of assumptions that the feed-in tariffs in both countries were found to approach cost-effectiveness. This result was not decisive, because the study was unable to establish financial values for energy security gains – which are likely to be relatively low –and technology cost reductions. However, a qualitative discussion of these themes showed that serious doubts still exist when all four areas of costs and benefits are considered cumulatively. Indeed, in most cases, where assumptions were made, it was chosen to err of the side of being over- rather than under-generous with respect to the potential benefits of feed-in tariffs – for example, assuming no leakage in the European ETS and identifying only additional employment and not net employment impacts. Similarly, costs focused only on feed-in tariffs and did not consider any other complementary spending to promote renewables, including investments in national infrastructure to accommodate increased renewable energy penetration. Taking these factors into account, this study shows that it cannot be established that current spending on solar PV in Germany and Spain is cost-effective.

This is a concerning finding. Amid international calls for a green economy, and resource and climate pressures on the transition to new energy systems, we should be sure when and how policies to promote renewable energy can be cost-effective. When we consider the increasing take-up of targets and mandates in developing countries, where fiscal resources are scarce, and there are many competing priorities, this is particularly important issue. More information is urgently needed about the actual returns on solar PV spending across a number of countries. In order to make this possible, it is equally clear that robust methodologies need to be proposed and discussed, such that deeper analysis can applied consistently across a range of countries.

Proving cost-effectiveness requires a relationship between feed-in tariffs and technology cost reductions to be proven and for it to be significant. Without such proof, policy-makers may wish to re-examine the share of their financial support granted to research, which is a very small fraction of the total including deployment. This does not suggest that research investment is sub-optimal at present: making the case to increase it requires *inter alia* an understanding of how it contributes to technology cost reduction, and what the capacity of the research activity is to usefully absorb more investment.

On a final and separate note, the study also shows something that will surprise few experts but must be emphasized nonetheless: there is no such thing as 'one' feed-in tariff. Depending on their design, different subsidies for renewable energy will operate more or less efficiently. By comparing two countries, for example, it can be shown that Germany pays significantly less per kWh of solar PV generation than Spain, once the average insolation of each country is taken into account. In the context of cost-effectiveness, if can be added – equally obviously – that there is no such thing as 'one' country. Different contexts matter and affect the potential benefits that subsidies for solar PV can provide, including dynamics such as carbon-pricing policies, the profile of energy systems being offset, the extent to which a country is well placed to generate economic benefits from its subsidy regime, resource richness or a country's particular energy security situation.

In sum, if countries are committed to subsidizing the deployment of renewable energy, further analysis of cost-effectiveness could – and should – usefully shed light on how these policies can be made more cost-effective, making better use of scare fiscal resources.

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