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Assessing the Cost-Effectiveness of Renewable Energy Deployment Subsidies: Solar PV in Germany and Spain

March 2012

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About GSI

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Acknowledgements

This study forms one of a series of three looking at the cost-effectiveness of renewable energy deployment subsidies, each one focusing on different technologies and countries. The increased deployment of low-carbon energy is one of the principal interventions required to avoid catastrophic climate change. At the same time, the success of deployment will depend upon government policy that is effective and that uses resources efficiently. This is central to maximizing the amount of renewables deployed given the resources that are available, and to ensuring that subsidies for renewables remain politically viable. These studies represent a first effort to develop an appropriate multi-criteria framework for evaluating the cost-effectiveness of renewable energy subsidies, taking into account all costs and the wide range of potential benefits. The evaluation of subsidy policies is a core function of the Global Subsidies Initiative (GSI) and this methodology will continue to be developed in the coming years. If you have any comments, questions or recommendations, please contact us via our website, http://www.iisd.org/gsi.

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1.0 Introduction

In the last decade, a growing number of countries have employed subsidies to increase the deployment of renewable energy technologies (RETs). The subsidies have been credited with a wide range of positive outcomes, and some advocate that more countries around the world should introduce similar schemes. The policies have also attracted critics, who question whether subsidies are the best way to achieve the stated policy objectives and whether the costs can be justified. This paper explores how policy-makers might go about assessing the cost-effectiveness of subsidies to solar PV technologies. How can they quantify subsidies for deployment? How can they measure the benefits that are achieved and assess their value?

In considering these questions, this paper focuses on deployment subsidies for solar PV in two European countries, Germany and Spain. Its primary goal is to better inform debates about cost-effectiveness by exploring the methods required to assess cost-effectiveness and by estimating the general magnitude and range of benefits in several key areas.

2.0 Methodology

This study assesses cost-effectiveness in two steps. First, we estimate 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. Second, we estimate the costs of the policies and ask if the identified outputs and outcomes can be thought of as having been achieved at a "reasonable cost," defined as the value of the benefits being equal to or greater than the cost of the policy.

The common objectives that governments set out to achieve by subsidizing the deployment of renewable energy are listed in Table 1, broken down into intended outputs and outcomes.

TABLE 1: DEPLOYMENT SUBSIDIES FOR RETS: A SUMMARY OF POLICY OBJECTIVES, INTENDED OUTPUTS AND INTENDED OUTCOMES

<table>
<tr><th>POLICY OBJECTIVES</th><th>INTENDED OUTPUTS</th><th>INTENDED OUTCOMES</th></tr>
<tr><td>Environmental goals:
• Mitigation of climate change
• Reduction of local pollution</td><td rowspan="4">Increased deployment of renewable energy</td><td>Renewable energy generation will offset carbon-intensive energy sources, resulting in less carbon dioxide emissions and reduced local air pollution.</td></tr>
<tr><td>Economic and social goals:
• Industry creation
• Job creation
• Regional development</td><td>Increasing deployment of renewable energy technologies can:
• Foster national industries, creating jobs in manufacturing, installation and operations and allowing for the export of RETs and related services
• Allow for the export of renewable energy to other countries
If the specific location of deployment is influenced, such impacts can also be used to promote the development of subnational regions.</td></tr>
<tr><td>Energy security goals:
• 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 other sources of supply, notably imported fossil fuels.</td></tr>
<tr><td>Development of RETs:
• Cost reductions</td><td>According to "learning-by-doing" models, as a rough rule of thumb costs will be reduced by a fixed percentage 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.</td></tr>
</table>

In addition to these general objectives, some countries state a specific target for the increased deployment of various RETs, and occasionally state targets for specific outcomes too—for example, absolute or relative amounts of biomass technologies deployed by a certain date, specific reductions in carbon dioxide emissions or ambitions for job creation. In this analysis, specific targets were not considered. Effectiveness was identified as the impacts of the policy with respect to each of the general objectives listed above.

The method then moves to explore cost-effectiveness by considering how the value of the achieved benefits can be estimated in financial terms, and comparing that to the estimated financial burden of the subsidies.

In conducting an exploration of this method, all monetary values were expressed in constant values, before discounting at a 3.5 per cent real discount rate. This social discount rate was chosen following the United Kingdom's HM Treasury (2011) and the European Commission (2008). The base year for the analysis is 2010 and all capacity added between 2000 and 2010 is considered in this analysis. It is assumed that the life of an installation is 25 years, with Spanish installations receiving support for the whole 25 years and German installations receiving support for only 20 years. Thus, some benefits continue to accrue in Germany despite the absence of support, reflecting the assumption that curtailment of support in the final five years of operation would not lead to the closure of an installation.

3.0 Assessing Outputs: Deployment

3.1 Germany

Germany's main support mechanism for solar PV is a feed-in tariff (FIT): a subsidy mechanism whereby renewable energy producers are guaranteed a fixed price for a set number of years. The FIT was first established in 1990 with the Stromeinspeisungsgesetz. This was then replaced in 2000 by the Renewable Energy Sources Act (Erneuerbare-Energin-Gesetz, the EEG). Germany has provided a number of supplementary support mechanisms for renewable energy, including the 100,000 Solar Roofs Program (HTDP) established in 1999, but this study considers only the EEG over the period 2000–2010.

Germany's EEG is widely considered to be a very successful policy instrument in incentivizing the deployment of renewable energy technologies. Between 2000 and 2010, around 17 gigawatts (GW) of capacity was installed, taking annual solar PV electricity generation from 60 gigawatt-hours (GWh) in 2000 to a total of around 11.7 terawatt-hours (TWh) in 2010.

3.2 Spain

Spain's main support mechanism for solar PV is also an FIT. It was first established in 1994, and further developed by the Electric Power Act of 1997 and the Royal Decree of 1998. The latter established that electricity generated by photovoltaic plants should be paid a guaranteed FIT, adjusted every quarter for new plants. Further modifications were subsequently introduced in royal decrees of 2004 and 2007.

Spain's FIT also succeeded in stimulating the deployment of solar PV, though it experienced a market boom in 2008, the result of which was drastically reduced levels of annual installed capacity in 2009 and 2010, following policy changes. Between 2000 and 2010, a total of 3.9 GW of capacity was installed, taking annual solar PV electricity generation from 18 GWh in 2000 to a total of around 6.4 TWh in 2010.

4.0 Assessing Outcomes

4.1 Environmental Impacts

Electricity generated from solar PV can reduce the environmental impacts associated with conventional energy technologies because it is less carbon- and pollution-intensive. Studies have estimated that the rate of life-cycle carbon dioxide equivalent (CO_2e) emissions for electricity generated from PV is between 25 and 80 grams CO_2e/kilowatt-hour (kWh) for silicon-based modules and as low as 24 grams CO_2e/kWh for cadmium telluride (CdTe) cells (Fthenakis, Hyung, & Alsema, 2008; Wiser, et al., 2011). Calculating the impact of increased deployment on carbon reductions and local air pollution is dependent on a number of factors: the source and amount of energy consumed during manufacture, the source of energy offset by the solar PV and the performance characteristics of the installation.

The time taken for a PV module to produce the amount of energy used in its manufacture, the Energy Payback Time, ranges from approximately 1 to 5 years (Masakazu, Keiichi & Kosuke, 2010; Fthenakis, Hyung, & Alsema, 2008) depending on the expected environmental conditions, the technology deployed and calculation methodology used. This is significantly less than the lifetime of the technology, with silicon PV modules typically being marketed with warranties of 20–25 years.

The source of energy offset varies by country. Since gas is generally the most easily dispatchable form of fossil electricity generation, and coal-based generation is the most common "new build" technology, it is likely that in most countries additional generation from solar PV would offset one or another of these sources, at least while renewables make up a relatively small percentage of the overall electricity mix. IEA data for 2008 reports that the CO_2 emissions from electricity generated from gas are 278 g CO_2/ kWh and 345 g CO_2/ kWh for Germany and Spain, respectively; and the emissions from electricity generated by coal are 827g CO_2/ kWh and 901 g CO_2/ kWh (International Energy Agency [IEA], 2010a). This indicates that, on average, solar PV that offsets conventional generation can reduce greenhouse gas (GHG) emissions by around 70–95 per cent. Therefore, although electricity from solar PV is not carbon-free, the savings are considerable.

In the context of Germany and Spain, it should be noted that the EU Emissions Trading System (EU ETS) co-exists alongside each country's national subsidies to promote renewable energy. This complicates matters, as the carbon price generated by the EU 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, Ritter and Schmidt (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 EU 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 EU ETS.

Various counter-arguments have been made in response to this criticism, contending that complementary tools are appropriate for a range of reasons, including the following:

- The EU ETS has been widely criticized for failing to create a price that adequately incentivizes low-carbon economic restructuring.
- The electricity market in many countries is not competitive enough to respond efficiently to a market instrument like the ETS.
- Various externalities surround innovation, which, if uncorrected, might lead a carbon price to more effectively incentivize reductions in consumption than investments in the development and installation of new technologies, which are essential to meeting medium- and long-term mitigation goals.
- From a political economy perspective, targeting emission reductions in the energy sector could be the most pragmatic way to drive through serious low-carbon economic restructuring, given political opposition to a high carbon price.

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. For further discussion of the issues of interaction between renewable energy and climate policies, see Philibert (2011) and Gonzalez (2007).

This study estimates 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 the estimates in light of the above concerns.

4.1.1 Estimating Offset Carbon Emissions

This study estimated the total amount of carbon emissions that would be offset by Germany and Spain to date (2000–2010) and across the total lifetime of the solar PV installed between 2000 and 2010. These estimates are summarized in Table 2, below.

The calculations assume:

- A 25-year project lifetime, with low and high sensitivities of 20 years and 30 years, respectively
- A carbon dioxide saving of 90 per cent of the generation displaced
- No interactions with other climate-related policies
- Low and high estimates of emissions offset, assuming either coal or gas was the predominant fuel displaced

Assessing the value of these offset emissions 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 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 carbon dioxide levels to 550 parts per million (ppm), from sources whose estimates ranged from US$135 to $380 (€105–295) by 2060 (International Monetary Fund, 2008). In order to illustrate how a cost-effectiveness assessment would vary under conservative and generous assumptions, low, medium and high values of €15, €50 and €200 were assigned on this basis.

TABLE 2. ESTIMATED QUANTITY AND VALUE OF OFFSET GHG EMISSIONS IN GERMANY AND SPAIN

	GERMANY				SPAIN			
	2000–2010	LIFETIME OF 2000–10 INSTALLED CAPACITY			2000–2010	LIFETIME OF 2000–10 INSTALLED CAPACITY		
		20 YEARS	25 YEARS	30 YEARS		20 YEARS	25 YEARS	30 YEARS
Total power generated (GWh)	29,945	234,651	292,825	350,999	15,654	98,426	122,787	147,147
Total CO_2 savings (million tonnes)	8-24	65 - 194	81 - 242	98 - 290	5-14	34 - 89	42 - 111	51 - 133
Total € billion of carbon saved at prices of:								
€15/tonne	0.13 – 0.39	0.76 – 2.26	0.88 – 2.62	1.03 – 1.02	0.08 – 0.22	0.40 – 1.05	0.48 – 1.27	0.54 – 1.42
€50/tonne	0.43 – 1.30	2.53 – 7.54	2.93 – 8.72	3.44 – 10.23	0.28 – 0.73	1.34 – 3.50	1.61 – 4.22	1.82 – 4.75
€200/tonne	1.73 – 5.20	10.13 - 30.14	11.73 – 34.89	13.76 – 40.92	1.11 – 2.90	5.36 – 14.01	6.46 – 16.89	7.26 – 18.99
Average value (€) per kWh of carbon saved at prices of:								
€15/tonne	0.00 – 0.00	0.00 - 0.01	0.00 - 0.01	0.00 - 0.01	0.00 – 0.00	0.00 - 0.01	0.00 - 0.01	0.00 - 0.01
€50/tonne	0.00 – 0.01	0.01 - 0.03	0.01 - 0.03	0.01 - 0.03	0.00 – 0.01	0.01 - 0.04	0.01 - 0.03	0.01 - 0.03
€200/tonne	0.01 – 0.02	0.04 - 0.13	0.04 - 0.12	0.04 - 0.12	0.01 – 0.03	0.06 - 0.15	0.05 - 0.14	0.05 - 0.13

		VALUE OF CARBON SAVED					
		GERMANY			SPAIN		
		20 YEAR	25 YEAR	30 YEAR	20 YEAR	25 YEAR	30 YEAR
Total power generated (GWh)		234,700	292,800	351,000	98,400	122,800	147,100
Total carbon saved (million tonnes)		59 - 175	73 - 218	88 - 261	31 - 80	38 - 100	46 - 119
Value of carbon saved (EUR billion)	15 EUR/t	0.8 - 2.3	0.9 - 2.6	1.0 - 2.9	0.4 - 1.1	0.5 - 1.2	0.5 - 1.4
	50 EUR/t	2.5 - 7.5	2.9 - 8.7	3.3 - 9.7	1.3 - 3.5	1.6 - 4.1	1.7 - 4.5
	200 EUR/t	10.1 - 30.1	11.7 - 34.9	13.1 - 38.9	5.4 - 14.0	6.2 - 16.2	6.9 - 18.1
Value of carbon saved (EUR/kWh)	15 EUR/t	0.00 - 0.01	0.00 - 0.01	0.00 - 0.01	0.00 - 0.01	0.00 - 0.01	0.00 - 0.01
	50 EUR/t	0.01 - 0.03	0.01 - 0.03	0.01 - 0.03	0.01 - 0.04	0.01 - 0.03	0.01 - 0.03
	200 EUR/t	0.04 - 0.13	0.04 - 0.12	0.04 - 0.11	0.05 - 0.14	0.05 - 0.13	0.05 - 0.12

In absolute terms, the estimates indicate that Germany's FIT has achieved higher carbon dioxide reductions than Spain's FIT and will continue to do so across the lifetime of currently installed capacity. In relative terms, the cost of offsetting carbon per kWh hour was relatively similar, though with both the lower- and upper-bound costs for Germany being lower than their counterparts in Spain. Given the lower levels of solar radiation in Germany, this suggests that Germany's FIT policy has performed more efficiently than Spain's. In both countries, the exact value of the gains achieved by the FIT is highly sensitive to the lifetime of the solar PV technology. If solar PV plants can continue to operate significantly longer than expected, then the amount of carbon dioxide that is offset will increase accordingly.

4.1.2 Estimating Local Air Pollution Impacts

Local air pollution impacts were not considered in this study, as the issue was not considered essential to an exploratory analysis: neither Germany nor Spain has explicitly targeted this policy, and neither country's tariffs were varied according to any air quality indicator.

Solar power can, however, certainly reduce emissions that are harmful to human health and the environment in ways that are unrelated to climate change, such as nitrogen oxide, sulphur dioxide, mercury emissions, volatile organic compounds and heavy metals (Jacobson & High, 2008).

Where fossil-fuel-based electricity generation plays a role in creating such pollution, its displacement by solar power could provide significant benefits. A report by the IEA (2011) provides a comparison of emissions from renewable and non-renewable technologies for two local pollutants (nitrogen oxide and sulphur dioxide). The report finds that, with the exception of biomass, renewable energy technologies have much lower emissions than fossil energy sources. Such benefits should be taken into account in a full assessment of cost-effectiveness.

4.2 Economic and Social Goals

Deployment subsidies often include a policy goal of encouraging sustainable economic growth, sometimes referred to in the context of a "green economy." This can be achieved in several ways. First, economic activity is created because of the installation and maintenance of the technologies themselves. Countries can also hope to promote domestic solar PV manufacturing industries—producing entire systems or system components such as wafers, cells, modules and Balance of System items—that are globally competitive, and can therefore go on to capture a share of the global solar PV market. Opportunities for such industries might become highly significant in the future as the costs of solar PV fall and deployment increases, especially if costs reach grid parity. Finally, where countries have particularly high levels of solar radiation, 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.

Estimating these economic benefits is complicated, however, and in order to be comprehensive we need 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 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. The so-called "merit order effect" may also increase the total benefits of renewable energy generation: by offsetting the most expensive marginal fossil-based energy generator, renewables can reduce the overall market price for conventional energy (Sensfuss, Ragwitz, & Genoese, 2007).

Some caution should be urged with respect to the potential future promises of solar PV, and indeed the volatility that surrounds the economic impact of subsidy policies. In the short term, recent reductions in Spain's solar PV subsidy have made it clear that the industry is still heavily reliant on FITs, with reports of 15,000 jobs having been lost in the sector between summer 2008 and February 2009 (Asociacion de la Industria Fotovoltaica, 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 per cent 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.

4.2.1 Benefits from Manufacturing

Germany has been relatively successful in developing a solar PV industry, currently representing around 15 per cent of the global manufacturing of modules and approximately 19 per cent of global polysilicon production (European Commission Joint Research Centre, 2010; author's 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 solar PV industry becomes increasingly mature, new entrants are likely to see the potential benefits reduced for an equivalent cost.

Protectionist measures, such as import tariffs or local content requirements, can also affect competitiveness by generating 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 global competitiveness of the industry. In practice, the extent to which such measures are possible is constrained by World Trade Organisation (WTO) law, and in the EU by competition law. So far, the approach taken by Germany and Spain has been to keep tariffs low, despite industry pressure (Kirkegaard, Hanemann, Weischer, & Miller, 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 among all competitive suppliers, not exclusively to 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 per cent in 2009 (European Commission Joint Research Centre, 2010) up from a very low base in 2005.

This fact can be uncomfortable politically. Deployment subsidies that do not discriminate between domestic and foreign players will provide only an indirect incentive to domestic manufacture, due to factors such as lower transport costs, ease of doing business and direct access to customers—in other words, deployment subsidies may well benefit foreign companies more than they do domestic ones.

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.

4.2.2 Economic Benefits: Jobs Created

A comprehensive assessment of the economic benefits of solar PV ought to identify net economic impacts. For the purposes of this exploratory study, such a large-scale analysis was not feasible. Instead, gross job creation alone was chosen to explore this issue area. Gross job creation is a simple indicator that can be used to explore some of the data and issues that are involved in a more comprehensive assessment; and it can also be used to highlight some of the weaknesses related to estimates of gross benefits, which can be easily misinterpreted.

The number of jobs was estimated using an indicator of jobs created per MW of capacity by specific activity (U.S. Department of Energy, 2008; Friedman, 2009), with each of these activities divided into those that could be performed globally, such as module manufacture, and those that are performed locally, such as installation. The number of jobs created in service of local capacity was estimated by combining local capacity additions with the jobs per MW for local activities, and the number of jobs created in service of the global market was estimated by combining global capacity additions with the jobs per MW for global activities and estimates for the global market share of each country (European Commission Joint Research Centre, 2010; author's calculations).

TABLE 3. JOBS CREATED

	JOBS CREATED			
	GERMANY		SPAIN	
	PROJECT LIFE	2000-2010	PROJECT LIFE	2000-2010
Total jobs created	540,100	306,200	96,000	44,400
Jobs to meet local demand	448,400	214,600	89,600	38,000
Installation	*189,700*	*189,700*	*30,900*	*30,900*
O&M	*258,800*	*24,900*	*58,700*	*7,100*
Jobs to meet global demand	91,700	91,700	6,400	6,400

The financial value of the jobs created by the policy in each country was estimated simply, by multiplying the number of estimated job years in each country by the average annual earnings in the electricity sector, with a sensitivity of ± 25 per cent (World Salaries, 2008). Based on an average German electricity sector wage of around €40,000, this resulted in an estimated value of €8.9 billion-€16.1 billion from 2000 to 2010 and of €13.3 billion-€24.0 billion across the lifetime in which currently installed capacity can benefit from the subsidy policy. In Spain, where an average electricity sector wage is roughly €42,000, this resulted in a value of €1.4 billion-€2.5 billion from 2000 to 2010 and €2.4 billion-€4.3 billion across the lifetime in which currently installed capacity can continue to receive the subsidy.

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 (International Centre for Trade and Sustainable Development, 2010), Germany was ranked as third and 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 United States, which, like Germany, have been pioneers in supporting the technology, were also highly placed in the survey of patent applications, whereas

Spain's solar PV subsidies only began to incentivize significant deployment after Royal Decree 436 was issued in 2004. Of course, underlying competitiveness or a generous policy regime can nonetheless overcome such a barrier, as in the case of China, which has been a highly successful "late starter" in seizing market share. R&D policy is also highly likely to play a significant role in determining technological competitiveness, making it difficult to distinguish the exact role of deployment policy.

4.2.3 Gross Versus Net Estimates

In interpreting these figures, however, it should be emphasized that the use of gross jobs as an indicator is far from ideal: it is likely to seriously over-estimate the positive benefits to Germany and Spain's economies. A preferable indicator would be to estimate the net impacts—both positive and negative—that FITs could have on employment across an economy.

There are two main reasons to suppose that negative impacts will also exist. First, the public resources being directed toward solar PV technology will no longer be spent elsewhere in the economy, with the result that we would expect economic activity in these areas 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. Second, most FIT 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 and 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 such premiums appear small, they can be expected to have impacts on competitiveness at an economy-wide level. Spain could be excepted from both impacts, since the government has controlled electricity prices for households in the past decade and paid for this by accumulating debt—but even this will affect employment across the economy in years to come, as resources are diverted to pay off the debts that have accrued.

Analysis from other studies indicates that the difference between gross and net jobs 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 per cent 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 per cent. 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 per cent; or an additional 120,000 jobs, with a little over 0.25 per cent additional GDP (Ragwitz, et al., 2009).

In a comprehensive analysis of the cost-effectiveness of renewable energy technologies, it is necessary to conduct a detailed modelling exercise to project the net change in employment.

4.2.4 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 guarantee of origin scheme, but as of yet there has been no major trade in renewable energy from either Germany or Spain, neither of which has yet achieved its own domestic targets under the EU's Renewable Directive, which is likely to be a prerequisite for international trade.

4.3 Energy Security

Energy security is another common target of renewable energy deployment subsidies: if the overall share of imported energy is reduced, the country will become less sensitive to threats such as price volatility, political instability in energy-exporting countries, competition for limited resources, industrial action, market manipulation and the disruption of infrastructure due to adverse weather, natural disasters or terrorism. In many world regions, such concerns are focused on liquid transport fuels. Nonetheless, the diversification of electricity generation can still contribute to increased energy security. The potential importance of electricity in energy security could also increase in the future if electric vehicles become a dominant form of motor transport.

In 2009, however, the proportion of electricity generated by solar PV was approximately 1 per cent and 2 per cent of total demand in Germany and Spain respectively (IEA, 2010b). 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.

It is difficult to estimate the energy security benefits that have been achieved by deployment subsidies to solar PV in Germany and Spain. A country's energy security situation is highly individual and assessments of security draw on many criteria and are often qualitative. Similarly, it is very difficult to assign financial value to whatever benefits can be identified. In the absence of a full analysis of Germany's 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 in both countries suggests a positive effect on energy security.

4.4 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.

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—"runaway grid parity."

There are significant challenges to estimating the cost reductions that might have been brought about by deployment subsidies. It is possible to map how average generation costs have developed over time, but no accepted method exists to determine how much of these costs might be attributed to a single country's deployment policy. It is also difficult to parse out the impacts that can be attributed to deployment policy and those that should be attributed to R&D policies or the efforts of private actors. According to one analysis of solar PV cost reductions, costs are estimated to have fallen by more than 90 per cent over the last 30 years, with 43 per cent of cost reductions being correlated with plant size, 30 per cent with efficiency and 12 per cent 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 R&D efforts.

The relationship between increased deployment and costs is typically 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. Most only take into account deployment (learning by doing), though some also attempt to factor in the influence of R&D (learning by searching). Such models are sometimes used to justify high-cost deployment subsidies on the basis of future cost reductions, though a cautious interpretation of results should be recommended 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 per cent (Strategies-Unlimited, 2003) and 26 per cent (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 100 GW. 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. In addition, bi-directional causation makes it difficult to determine which cost-improvements have taken place because of deployment and which cost-improvements have themselves driven deployment, such that the estimated impact of changing the variable "deployment" may be smaller than projected.

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 include component-learning hypothesis (Ferioli, Schoots, & van der Zwaan, 2009) or technical evaluations of opportunities for cost reduction (Sinke et al., 2009), but even where these corroborate estimated potential cost reductions, they do not necessarily argue the case for a causal effect of deployment on cost reductions.

Third, on a pragmatic level, many cautionary tales exist about industries that have argued for 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 1954 that it will soon be economically competitive, yet it 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 the production of solar systems and R&D by increasing cell efficiency.

One final question of interest in exploring deployment subsidy cost-effectiveness is to ask, what is the most efficient share of funding between deployment and R&D in stimulating cost reductions? There is no rule for the ideal balance, but simply reporting on relative spending in each area may help inform policy-makers. In Germany, for example, the BMU had an R&D budget for solar PV of €32.1 million in 2007 (Global Green, 2009). During the same year the total cost of the solar PV FIT was around €1.5 billion, and the total spending commitment made to newly installed capacity in 2007 was approximately €8 billion (author's calculations). The measure could be improved by a more comprehensive survey of potential research and development funding, as total spending on R&D from all possible ministries and agencies may be closer to spending on deployment. The *World Energy Outlook 2010*, for example, identifies a global total of over US$7 billion of government spending on solar PV deployment subsidies in 2009, versus US$3 billion of public and private spending on research and development (IEA, 2010c).

5.0 Outputs and Outcomes Summary

To assess whether the subsidies have had their desired effects, each of the goals listed earlier is now presented in Table 4, alongside exploratory estimates of the actual outcomes of the policies, where available.

TABLE 4: SUMMARY TABLE OF EFFECTIVENESS OBJECTIVES, OUTPUTS AND OUTCOMES[1]

<table>
<tr><th>POLICY OBJECTIVES</th><th>OUTPUTS</th><th>INTENDED OUTCOMES</th><th>ESTIMATES OF ACTUAL OUTCOMES</th></tr>
<tr><td>Environmental goals:
• Mitigation of climate change
• Reduction of local pollution</td><td rowspan="4">Increased solar PV capacity and electricity generation:

Germany:
• 17.2 GW of capacity added from 2000–2010
• 29.9 TWh of generation in 2000-2010
• 292.8 TWh of generation estimated across lifetime of capacity installed

Spain:
• 3.9 GW of capacity added from 2000-2010
• 15.6 TWh of generation in 2000-2010</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:[2]
Germany: 81–242 megatonnes (Mt) CO_2
Spain: 42-111 Mt CO_2
No estimates developed for local pollution.</td></tr>
<tr><td>Economic and social goals:
• Industry creation
• Job creation
• Regional development</td><td>Increasing deployment of renewable energy technologies can:
• Foster national industries, creating jobs in manufacture, installation and maintenance, and allow for the export of RETs and related services
• Allow for the export of renewable energy to countries that are not generating enough renewable energy to meet their own targets

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):
Germany: 14.3%
Spain: <1%

Share of global polysilicon production (2009)
Germany: 19%
Spain: <1%

Cumulative "job years":
Germany: 540,100
Spain: 96,000
Patent activity ranking:
Germany: 3rd
Spain: 17th</td></tr>
<tr><td>Energy security goals:
• 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, and thereby improving its energy security.</td><td>Proportion of electricity from solar PV:
Germany: 1%
Spain: 2%
No appropriate indicators identified for broader contribution to energy security.</td></tr>
<tr><td>Development of RETs:
• 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>
</table>

[1] All outcomes are estimated assuming that the solar PV installations have an average 25-year lifespan.
[2] Uncertainty regarding offset CO_2 emissions is dependent on the fuel type being offset: at the lower end, gas, and at the higher end, coal.

Overall, the indicators suggest that the subsidy programs—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 R&D, Germany is rated as having a greater number of patents and therefore likely to be more successful as an international hub for research and development, though it is not clear if this is a result of its deployment policy or other policies in support of R&D and innovation.

Having established the extent to which both deployment subsidies appear to have been effective in achieving their intended outcomes, it can then be asked if the policy can be considered cost-effective— were its objectives achieved at a "reasonable cost"?

6.0 Cost-Effectiveness

6.1 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 2010. Each cohort of installations was then assumed to receive the 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) and the IEA (2010b). Data for the weighting of the tariff bands came from Renewables Insight (RENI, 2010) and Segaar (2010). Data on FIT 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 and 2010, 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. In Spain, recent developments related to retroactive subsidy cuts are not included, as these were confirmed only after the analysis was completed. Projected costs in Spain are, therefore, based on original policy design.

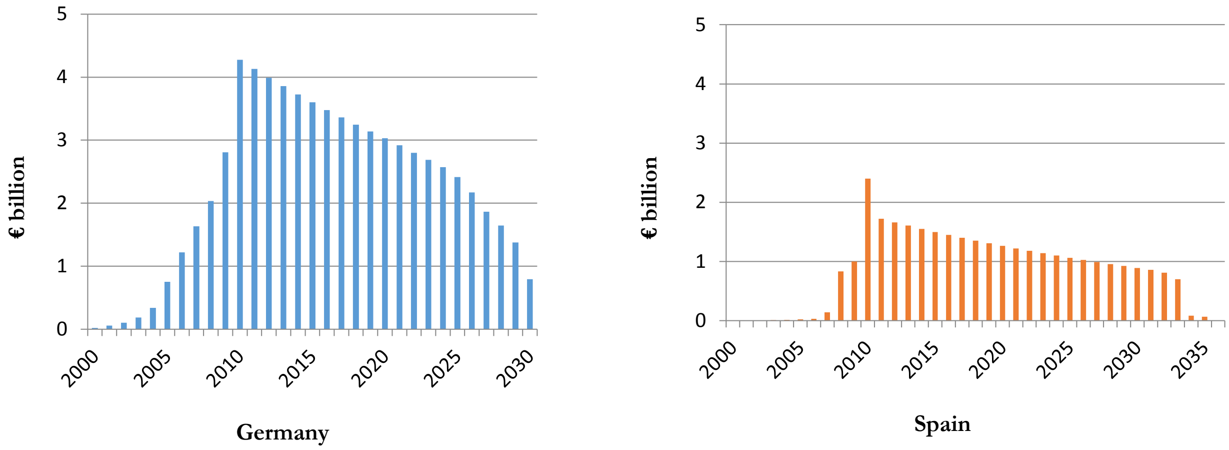


FIGURE 1: ESTIMATED SUBSIDY EXPENDITURE BY YEAR

Note: Expenditure expressed in 2010 euros and discounted at 3.5 per cent real discount rate. The large drop in expenditure in Spain from 2010 to 2011 is due to very high levels of average solar radiation in 2010 and an assumption of average levels of solar radiation for each future year across the policy's lifetime.

TABLE 5: KEY INDICATORS OF THE LIFETIME FINANCIAL COST OF SOLAR PV DEPLOYMENT SUBSIDIES

	GERMANY	SPAIN
Total commitment support to solar PV installed during 2000–2010 (€ billion, discounted values)	70.2	32.3
Total TWh of electricity generated (25 years)	292.8	122.8
Total cost per kWh (€/kWh)	0.24	0.26
Yearly average solar yield (kWh/kWp/yr)	950	1,300

Source: author's calculations. Data on average solar yield from European Commission (2010).

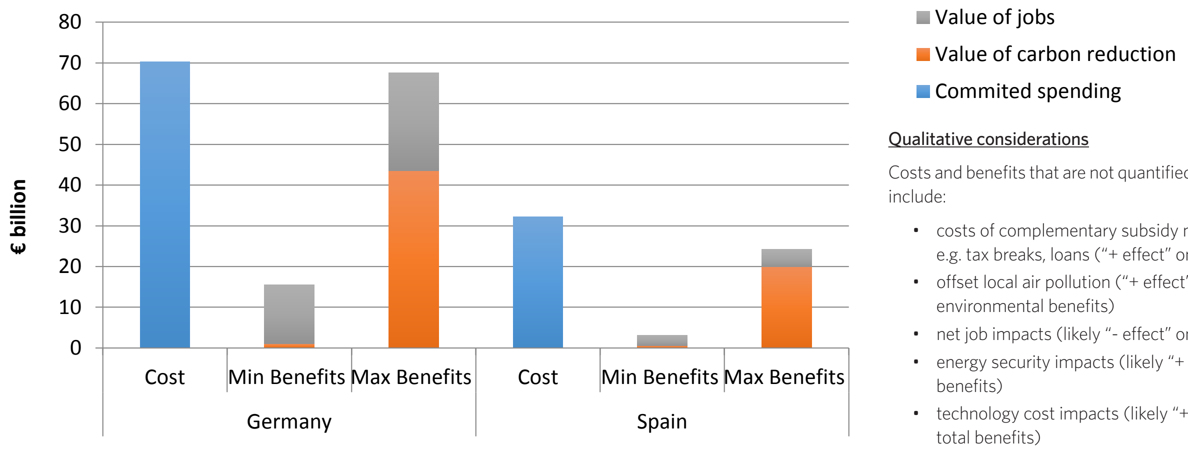
The estimates show that, as of 2010, the total spending commitments made by Germany's FIT for solar PV, €70.2 billion, were a little over twice as costly as Spain's, at € 32.3 billion. They also show that Germany's policy is the more cost-effective of the two, particularly taking into account the average solar yield in each country.

6.2 Absolute Cost-Effectiveness

Studies looking at the cost-effectiveness of solar PV have often focused on one particular outcome being targeted by the policy (Frondel, Ritter & Schmidt, 2008; Álvarez, Jara, Julián, & Bielsa, 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.

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 costs and benefits per kWh of power generated for each country. The extreme of either end is unlikely—the true value probably rests somewhere between the two.

The cost was calculated as summarized above, based on a policy lifetime of 20 years in Germany and 25 years in Spain. Benefits were compared assuming an average technology lifespan of 25 years in both countries. The financial benefit of carbon savings was estimated as reported in section 4.1, according to a minimum and maximum carbon value of €15 and €200, respectively. The financial benefit of an average job in the solar PV industry was estimated as reported in section 4.2, using a gross jobs estimate based on the average annual earnings in the electricity sector, with a sensitivity of ± 25 per cent, and not taking into account net impacts (World Salaries, 2008). As explained in sections 4.3 and 4.4, it was not possible to estimate the value of benefits related to energy security or technology cost reductions, so the value of these benefits was not included. The likely direction of the effect of all non-quantified impacts is summarized alongside the comparison of subsidy costs and benefits in Figure 2.



Qualitative considerations

Costs and benefits that are not quantified and compared include:

- costs of complementary subsidy mechanisms, e.g. tax breaks, loans ("+ effect" on costs)
- offset local air pollution ("+ effect" on environmental benefits)
- net job impacts (likely "- effect" on job value)
- energy security impacts (likely "+ effect" on total benefits)
- technology cost impacts (likely "+ effect" on total benefits)

FIGURE 2: GRAPH INDICATING COST AND VALUE OF SOLAR PV SUBSIDIES OVER PROJECT LIFETIME FOR PROJECTS INSTALLED BETWEEN 2000 AND 2010

In addition to the qualitative considerations identified in the key, it should be noted that the overall value of the benefits with respect to solar PV is highly sensitive to the lifetime of the technology.

The value of offset carbon emissions is another particularly sensitive 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 around €320 per tonne (author's 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. A carbon price of between €200 and €320 per tonne is relative among estimates of the true value of carbon, and numerous alternative investments could be used to reduce carbon at lower costs. This shows that carbon savings alone do not make either Germany or Spain's solar PV deployment policy cost-effective. In addition, it should be noted—as described more fully in section 4.1—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 being emitted across the system, the carbon price will lower, resulting in an emissions trading system that incentivizes fewer carbon reductions.

Uncertainty regarding economic benefits may also affect outcomes. As with carbon prices, the range between the minimum and maximum estimate is considerable, depending 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 centralized 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. Moreover, as an exploratory study, this analysis was only able to develop an indicative estimate based on an assessment of gross job creation, which may be misleading, as it fails to take into account multiplier impacts and net impacts due to the resources that have been redirected from other parts of the economy. It is likely to represent an upper bound of potential economic benefits.

The two missing elements in this comparison of costs and benefits are the values of energy security impacts and technological innovation. In an exploratory analysis, it is not possible to establish indicative estimates for such complex issues, except for fairly broad generalizations. Attempts to estimate the scale of financial benefits may do more harm than good unless significant methodological uncertainties can be addressed, and may be best restricted to a complementary qualitative analysis. Nonetheless, the financial value of these benefits, in particular technological cost reductions, could potentially bridge the gap between the costs and benefits in each country, even under conservative assumptions.

Overall, this analysis shows that it is challenging to develop a rigorous cost-benefit analysis of renewable energy deployment policy. At the same time, the exploration of such an analysis in the case of Germany and Spain shows that it cannot be taken as self-evident that the costs of a renewable energy deployment subsidy must be worth the benefits: both maximum and minimum sensitivities show the costs to be above the likely range of quantifiable environmental and economic benefits, and this with a likely overestimation of economic benefits and potential underestimation of costs. Given the high absolute costs of the schemes—€70.2 billion in Germany and €32.3 billion in Spain—this suggests that a stronger evidence-based understanding of the benefits that are being achieved by these subsidies would be desirable.

7.0 Conclusions

This study estimates that the solar PV technology installed between 2000 and 2010 in Germany and Spain has committed each country to spending €70.2 billion and €32.3 billion, respectively, through their FITs. The very size of this obligation reflects the success that each policy has experienced in stimulating solar PV deployment, which in 2009 represented 1 per cent and 2 per cent of electricity generation, respectively.

In attempting to conduct an exploratory cost-effectiveness analysis, this study yields more methodological findings than it does concrete conclusions. The primary finding is that such analysis, if pursued earnestly, is extremely difficult to perform in a robust and comprehensive manner. 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. In some cases, the uncertainty leaves policy-makers with a large range of possibilities to consider. In others, attempting to quantify a financial value for costs and benefits was considered unviable, at least as part of an exploratory analysis. Yet without at least reviewing all of these areas, any analysis will be incomplete and risks misrepresenting the true scale of costs and benefits of renewable energy deployment policy.

Reasonable efforts can be made to estimate some key costs and benefits: subsidy spending, environmental and economic impacts, and the financial value of environmental and economic impacts. By these measures alone, it was only under the most optimistic of assumptions that Germany and Spain's FITs for solar PV began to approach cost-effectiveness. This result is not decisive, because the study was unable to establish indicative values for energy security gains—which are likely to be relatively low—and technology cost reductions, which may be significant. However, it does suggest that, for such costly policies, there ought to be a clearer understanding of the likely scale of benefits in each area of impacts. In particular, establishing the cost-effectiveness of solar PV deployment may require the development of better methods for estimating the relationship between a FIT and technology cost reductions, or to at least consider qualitatively the best balance between deployment subsidies and R&D.

Amid international calls for a move to green economies, and as resource and climate pressures continue to drive the transition to new energy systems, governments should have an understanding of when and how renewable energy deployment policies can be cost-effective. This is a particularly important issue in light of an increasing take-up of targets and mandates in developing countries, where fiscal resources are scarce and there are many competing priorities for public funds.

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 scarce fiscal resources.

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