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Photovoltaic investment roadmaps and sustainable development

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ABSTRACT

This paper analyzes the potential contributions of photovoltaic energy to sustainable development in its three dimensions, environmental, economic, and social. For that purpose, the capacity deployments proposed by the main international institutions in the field are considered, mainly the International Energy Agency. The paper focuses on the monetary valuation of avoided CO_2 emissions, and the assessment of the required financial funds. The risk implied by the uncertain photovoltaic prices are dealt with, and methods to manage it are suggested. It is shown that valuing emission at a conservative price and properly discounted, would be enough to finance, on average, the required investments: thus, a low carbon tax is all that would be required to finance the investments.

1. Introduction

This paper analyses several aspects of the photovoltaic (PV) energy technology in relation to sustainable development. The paper has a macro focus, in that it considers the PV deployment roadmaps of several international institutions, mainly the International Energy Agency (IEA). The concept of sustainable development embodies three dimensions - see, for (e.g., Gonzalez et al., 2015) -, economic, environmental, and social, all of them discussed to some extent. First, the environmental dimension is analyzed by calculating the monetary value of avoided CO_2 emissions (CO_2e). This involves fixing at least four set of values: the appropriate discount rate for social projects, the monetary value of CO_2e - i.e., the price of, for e.g. 1 Tn. of CO_2e -, the conversion rate of energy generated into amount of CO_2e, and the depreciation rate of the PV investment. The first two are highly debatable, although some consensus may be reached - see (Drupp et al., 2015; Isacs et al., 2016; The World Bank, 2015) -, whereas the last two are more of a physical nature and therefore the values are better known.

Regarding the economic dimension, the paper focuses on the financial requirements of the projected investment in the published roadmaps. This has been one main concern in the COP 21 in Paris, and a preliminary estimate of the funds required for the commitments made by participating countries yields a value close to 4 trillion US $ for renewable capacity (IEA, 2015a); 1.2 trillion for the sun energy, mainly PV. One relevant characteristic of the PV energy to be accounted for in this assessment is the strong learning rate (LR) shown by this technology in the last 35 years; in fact, most available estimates give a minimum value of 20%, and some set it at 25% (Mauleón, 2016). Then, as capacity is deployed costs decrease, so that faster deployment paths will induce faster cost decreases, implying that they will not necessarily lead to an increased volume of funds - see Section 3.2. But another crucial point to be discussed is the uncertain value of this LR. Several authors have noted that this should be dealt with in the simulations (Nordhaus, 2014; Rubin et al., 2015; Wiesenthal et al., 2012), and this has been done here, conducting the simulations with the estimation results for the PV LR model. This introduces uncertainty in the results, which is always a main concern in financial analysis, and some concepts and measures to manage it are introduced and implemented (Dowd, 1998; Jorion, 1997). Finally, and with both results, the monetary value of avoided CO_2e, and the required financial funds, a cost benefit analysis is conducted.

The analysis of the transformation to a cleaner and more sustainable energy system can be approached in several ways. One widely implemented is the IEA's model (Loulou, 2008; Loulou and Labriet, 2008; Loulou, 2016): succinctly, a bottom up model of the whole energy systems is built, the solution being obtained by the minimization of the current discounted value of all future energy costs, derived from the investment decisions of optimizing agents in competitive markets. Paths for all energy sources are derived, and the solution can be adapted by changing the forcing, or exogenous, assumptions notably growth rates, prices of some resources,

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taxes and subsidies. It is in this framework that the analysis of subsidies to fossil fuels and renewables can be appraised. Many other refinements can be introduced as well, as explained in detail in the pertinent documentation (Loulou, 2016). Similar global approaches are followed by other research institutions (notably, GP int. 2015; Irena, 2016a, b; Grantham Institute, 2017).

This approach is rich in detail and yields generally useful results and guidance for governments. Yet, it quickly becomes very complex, and that prevents a detailed treatment of certain relevant points like: 1) the randomness of key parameters and assumptions, in order to model our limited knowledge about them, 2) technologies learning rates, and this applies specially to renewables sources, mainly wind and PV, 3) the social cost of CO_2 emission and other pollutants. All these points and others are discussed in the methodology and can be somewhat dealt with, but inherent difficulties in the proposed framework prevent or make computationally almost impossible a full treatment - see again, (Loulou, 2016), specially chaps. 7, 8 and 11). The approach followed here can be thought of as complementary, in that it allows a straightforward analysis of the three points mentioned, taking as starting point the investment path derived from the simulation of the fully-fledged model.

The paper is organized as follows: Section 2 explains the methodology and discusses the values required for the monetary valuation of CO_2e; Section 3 presents the required theoretical support to value the emissions, the required financial funds, and to manage the risk derived from the uncertain future PV prices; Section 4 presents the results obtained with the previous methodology, and Section 5 discusses several aspects of the PV technology in relation to sustainable development. Section 6 finally, concludes and points to some topics for future research.

2. Material and methods/Methodology

This section deals with several aspects required to select the final values to be plugged in the calculation of a monetary value for the CO_2 emissions (CO_2e) avoided by any projected path of PV investment. Two of them are purely economic issues - the correct price of CO_2 emissions, and the social discount rate - and there is not an agreed general consensus about them. Some reasonable values can be drawn from an analysis of the relevant literature, nevertheless - Sections 2.1,2. The remaining two questions - the rate of depreciation of PV investments, and the equivalence between CO_2e and Kwh. -, are more of a physical nature, and although there are discrepancies, they are reasonably bounded - Sections 2.3,4.

2.1. Valuing CO_2 emissions

One approach to put a price on CO_2 emissions is to look at the actual prices that several countries put on it, i.e., carbon taxes. A recent survey and analysis is presented in Kossoy et al. (2015), where a huge dispersion on taxes implemented by different countries is shown, between 1 and 130 US $ per Ton. of CO_2. The Swedish value of 130 is somewhat of an outlier, and a further analysis shows that 99% cases are below 30 US$, and 85% under 10 US$. These values are considerably lower than the theoretical values reported in scenario analysis, that yield values, on average, between 80 and 120 US $/t$CO_2e$ consistent with the goal of limiting global warming to 2 °C (Clarke et al., 2014).

A recent and thorough discussions of this point is presented in Isacs et al. (2016). The authors consider two basic approaches, based on the Marginal Abatement Cost (MAC) and the Social Cost of Carbon (SCC). The first could be measured by the actual carbon taxes implemented by a government assuming that it is efficiently calculated, which does not seem to be the case in practice. Then, the approach based on the SCC is to be favored. The authors also note that whatever the methodology, the correct price must be increasing with time, given that the volume of CO_2 in the atmosphere increases as well. In other words, given that energy investments last for decades, it is the evolution of the price of emissions over that lifespan that should matter. Finally, they provide survey values, with minimum and maximum average reported values in the literature. The minimum values reported are 6.1€ and 13.4€ for the years 2015 and 2050 respectively (6.7, 14.7 US $ applying a conversion rate of 1.1 US $ per euro €). The maximum values reported are rather high compared to other published values in the literature.

A further alternative would be to take the market value of the emission rights, in some organized market like the European Emissions Trading Scheme (ETS). However, this value is much affected by possible economic downturns, and by the volatility of energy prices notably natural gas, since the emission factor of this energy source is substantially lower than other alternatives like coal and oil.

A rather conservative choice has finally been made, and the minimum values provided by Isacs et al. (2016) have been selected for the analysis. It will be shown that, even under this low valuation, the Social Cost of the CO_2 avoided by the investments projected in the IEA (2014) PV roadmap, is sufficient to justify the financial funds required, even in the worst uncertain scenario - see Section 5.1.

2.2. The social discount rate (SDR)

In a recent paper, Drupp et al. (2015) conduct a survey eliciting answers from experts in the field of social discounting. They find a mean (median) recommended value of 2.25% (2%), for social discounting in the long run. They also report considerable disagreement over specific values, although 92% lie in the interval 1%–3%. This lends support to the average values reported - mean and median-, and at the same time runs counter to the IPCC's (2014) conclusion that there is '*a broad consensus for a zero or near-zero pure rate of time preference*' among experts in the field - Kolstad et al., 2014. Interestingly enough, these results are also close to those reported by Giglio et al. (2015) on long term discount rates in the Singapore and UK housing markets, based on revealed evidence for claims on leaseholds, which yield discount rates lower than 2.6%. There are other values put forward by prominent economist in the academic and public debate, notably, 4.5% by Nordhaus (2008), and 1.4% by Stern (2007). Both values are rather extreme when compared with the averages of the Drupp's et al. (2015) survey.

A previous survey and formal analysis is that of Weitzman (2001), that reports corresponding 4% (3%) values for the mean and median respectively. These values are considerably higher than those of Drupp et al. (2015), although these authors give a detailed number of reasons to justify theirs - among them, a wider audience, up to date, more precise questions, etc. Another quite interesting result of Weitzman (2001) is that he provided a justification for a decreasing social discount rate and explained how to calculate it. In fact, and by applying Weitzman's methodology, a more recent work Evans (2008) provided a complete set of values for future social discounting. Evans' values relevant to the horizon considered in this research are, 3.5% for $t < 30$ y, 3.0% for 31 y$< t < 75$ y, and, 2.5% 76 y$< t < 125$ y.

As in the valuation of CO_2 emissions, this is a debated issue but perhaps with better defined boundaries. The values and analysis of Drupp et al. (2015) are the more up to date, and being based on a kind of meta-analysis can be taken as the more relevant - Giglio et al. (2015) give similar values. Although the median value in

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