Renewable and Sustainable Energy Reviews 49 (2015) 610–628

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Profitable climate change mitigation: The case of greenhouse gas emission reduction benefits enabled by solar photovoltaic systems

Christian Breyer [a,*], Otto Koskinen [a], Philipp Blechinger [b,c]

[a] Lappeenranta University of Technology, Skinnarilankatu 34, 53850 Lappeenranta, Finland
[b] Reiner Lemoine Institut gGmbH, Ostendstraße 25, 12459 Berlin, Germany
[c] Berlin Institute of Technology, Department of Engineering, Fasanenstraße 89, 10623 Berlin, Germany

ARTICLE INFO

Article history:
Received 6 November 2014
Accepted 21 April 2015

Keywords:
GHG emissions
Avoidance costs
Climate change mitigation
solar photovoltaic

ABSTRACT

In a world constrained by climate change, it is of utmost relevance that energy technologies offer a low level of greenhouse gas (GHG) emissions at a comparatively low cost level. A literature overview is presented, which shows that the common view of PV systems contradicts its position as an economically viable key solution in reducing greenhouse gas (GHG) emissions. However, most of the found research is outdated and instead of being a region-oriented specific analysis, most of the research has focused on general cost level calculations. A simple methodology is introduced for estimating the climate change mitigation relevance of PV systems by calculating the avoided GHG emissions for specific representative PV applications in respective regions. The potential of GHG mitigation by PV systems is combined with the related economics based on discounted cash flow calculus. PV applications ranging from small PV systems in rural off-grid regions up to large scale PV power plants and commercial PV rooftop systems show financial benefits for avoided GHG emissions. Even in Germany, the costs of avoiding GHG emissions using residential rooftop systems are 17–70 €/tCO_{2eq} depending on the applied assumptions. These costs are distinctly lower than the 80 €/tCO_{2eq} threshold for the cost of climate change impacts. PV power plants in Germany show financial benefits of 19–93 €/tCO_{2eq} for avoiding GHG emissions. Summing up, PV systems are a highly attractive climate change mitigation option.

Contents

Abbreviations: Capex, capital expenditures; CCS, carbon capture and sequestration; EPIA, European Photovoltaic Industry Association; EU ETS, EU Emissions Trading Scheme; GHG, greenhouse gas; IEA, International Energy Agency; IMF, International Monetary Fund; IPCC, Intergovernmental Panel on Climate Change; LCOE, levelized cost of electricity; NREL, National Renewable Energy Laboratory; PV, photovoltaic; RE, renewable energies; WACC, weighted average cost of capital

* Corresponding author. Tel.: +358 50 443 1929.
E-mail address: christian.breyer@lut.fi (C. Breyer).

http://dx.doi.org/10.1016/j.rser.2015.04.061
1364-0321/

1. Motivation

Growth rates of new installed photovoltaic (PV) capacities have been high for the last decades and may remain so for the decades to come [1,2,3]. A major driver for this increasing share of PV in the global power supply is the ecological limit of our planet Earth [4]. GHG emissions have been identified as the major threat for a collapse of the globalized human civilization in this century [5,6]. The absolute amount of annually emitted anthropogenic greenhouse gases (GHG) has steadily increased also during the previous decade. If the mitigation efforts are delayed, achieving low longer-term emissions becomes more difficult, and mitigation options are narrowed. For keeping the climate change impacts more or less under control, the 2 °C target has now been commonly accepted, i.e. temperature increase due to human activities needs to be limited according to this fundamental threshold [5]. As a consequence, GHG emissions need to be radically reduced, in particular those of the power generation system. A zero GHG emitting economy needs to be realized, the sooner the better [7].

Renewable energies exhibit very low specific GHG emissions, the major fraction thereof is still caused by the conventional energy system and will be automatically reduced alongside the progress of the global energy transformation. For the special case of PV two factors are decisive. Firstly, the cumulative energy demand for PV systems is steadily decreasing by about 14% per each doubling of historic cumulated capacity according to the energy learning curve [8]. Secondly, by using an increasing fraction of low carbon energy sources in the production of PV systems, one can reach a considerable progress in reducing the specific GHG emissions of PV systems [9]. Alongside the renewable energy technologies PV had been commonly considered as the most expensive power generation option [10]. The latest dramatic decrease in PV prices has changed this and PV is now competitive among other renewable and conventional power systems [11]. According to the report solar PV is being installed in several regions around the world without the aid of subsidies. Chile, Rwanda and Spain have such projects ongoing for MW class PV power plants, whereas in developing economies such as Kenya smaller household systems are being installed. Deutsche Bank confirmed that at least 19 markets were at grid-parity (power generation cost of solar PV is the same or lower than local retail electricity price) by January 2014 [12]. The consultant Eclareon stated that commercial solar PV's cost reaching retail electricity prices in several countries [13]. PV manufacturer REC Solar reported high profitability of self-consumed PV electricity in the retail, manufacturing and industry sectors, with 20–40% return on equity in Germany, Italy and Turkey [14]. The high competitive edge of solar PV for end-users had previously been expected [2,15,16] and is now confirmed by financial analysts, consultants and solar companies in different markets all around the world. The rapid decreasing in PV system prices underlines the scientific need to determine the GHG emission costs and benefits of PVs for different applications. After calculating the costs or benefits of each avoided ton of GHG emissions, we can choose the most economical GHG avoidance technologies for a specific region.

An often used instrument to compare different technologies is the avoidance costs curve. It has been simulated and calculated globally and for different single regions to give deeper insights and the most suitable reduction option [17,18,19]. McKinsey & Company [18] and Bloomberg [19] estimated the abatement costs to be under 60 €/tCO_{2eq} and 70 €/tCO_{2eq} for utilizing various different low carbon technologies. Financial discount rates of 4–6% were used for these estimations. Nevertheless the methodology of abatement curves shows some weaknesses [20,21]. Most of the limitations are based on the need of using assumptions and predictions for future avoidance curves as well as in the controversy about the correct capital costs [22,23,24]. In addition, the measurements are only individually studied instead of looking at synergetic effects. The different methodologies we examined were notably diverse in nature, and based on their evaluation, we propose our own methodology for calculating GHG avoidance costs and benefits and provide case examples using the most recent data available.

To understand the relevance and the scale of different technologies' GHG abatement costs, they have to be compared to some major thresholds. It was clearly stated in the Stern report that the cost of climate change impacts are about 80 $€_{2014}$/tCO_{2eq}[1] for the case of not violating the 2 °C target [6]. Compared to previously mentioned studies by McKinsey and Bloomberg, a lower financial discount rate of 0.1% was used in the Stern report. The European Emission Trading Scheme (ETS) is expected to induce a path for decreasing GHG emissions starting at about 30 €/tCO_{2eq} [25]. Similar numbers are derived in the US and internationally accepted [26]. Initially the cost of GHG emissions have been expected to range between 40 and 100 €/tCO_{2eq} for the EU ETS [27]. An analysis by consultant Pöyry [28] concludes that the carbon intensity of power sector in the EU can be reduced from 350 to 150 gCO_{2eq}/kWh by 2030 with a carbon price of 70 €/tCO_{2eq}. In the Energy Technology Perspectives 2014 by the International Energy Agency (IEA) [29] it is stated that for the 2 °C scenario in 2050 mitigation measures with costs up to 126 €/tCO_{2eq} are more cost effective to implement than emitting the equivalent greenhouse gases. The abovementioned thresholds can be regarded as cost limits for preventing the climate change mankind is facing. In the long run, a climate change mitigation technology would be highly attractive for no induced extra cost but for a financial benefit of avoided GHG emissions. The debate whether ETS or feed-in tariffs

[1] Converted from US dollars in 2000 applying inflation rate of 1.5% and conversion factor of 1.35 USD/EUR.