Solar PV Electrification in New Regions: International Low-carbon Energy Transition

BY HYUN JIN JULIE YU

Introduction

Energy is a basic component of human life, economic activity and civil progress and thus directly associated with national security and socio-economic development. The energy sector is undergoing a transformation and these changes would lead to public risks, uncertainty and challenges in the future energy systems. However, over 1.3 billion people in the world still have no access to electricity. The international community has been sharing the concern on how to address energy poverty issues and improve the global sustainability.

Solar photovoltaic (PV) energy has caught the eye of many governments as one of the front-runners of low-carbon technologies. Solar PV systems have experienced strong market growth and gained economic competitiveness over the last decade mainly supported by the national political reaction to the low carbon energy transition. The world cumulative installed solar PV capacity has been largely increased from around 600 megawatts (MW) in early 2000 to more than 400 gigawatts (GW) in 2018. The global module prices have declined significantly thanks to the globalization of the sector and this has helped enhance the economic competitiveness of PV systems. Module prices have been declined by a factor of about 10 since 2005 and they are now below € 0.3 per Watt Peak (Wp). Despite these favorable conditions, however, the global PV market recently went through a chaotic time due to the overproduction of PV products, fierce price competition and long-lasting trade disputes. The nation-wide approach to creating market demand is somehow limited in responding to the globalized PV industry capacity. Thus, there is a necessity to develop new PV markets.

In this context, this article aims to present a new approach to extend the international energy transition to diffuse low-carbon energies (e.g., solar PV) in new regions. It aspires to further deploy solar PV systems in less developed and developing countries, which are faced with energy poverty problems. The original contribution of this study is to extend the nation-wide vision of energy transition through renewable energies (e.g., solar PV) to an international perspective. This study provides the economic rationale of international energy transition mechanisms based on the case of the diffusion of small PV systems with Li-ion batteries. This study highlights the global economic benefits as a response to the current global PV industry crisis (new market) and the return on PV investments in the new regions.

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Traditional way of thinking: nation-wide low-carbon energy transition & globalization effects

Over past decades, climate change has been the subject of serious international negotiations and transforming the energy system via de-carbonization is an important target of international energy policy. However, each government has a different approach or priorities to deal with these issues. The objectives in solar PV policy mechanisms will differ from one region to another according to the political strategic position, regional or national contexts and history.

Until recently, the policies to achieve the low-carbon energy transition in many countries has aimed to create a nation-wide virtuous circle of innovation between the supply-side (R&D and industry) and the demand-side (markets) to reduce costs. Watanabe's 'virtuous circle' provided a theoretical support to these policy initiatives to create the technology innovation process. It asserted the creation of a 'virtuous cycle' between R&D, market growth and price reduction for PV development based on an empirical analysis of Japan's PV development [2].

Germany has shown a good example of the mechanism that creates a national virtuous circle of innovation Figure 1. The country began to promote the use of renewable energies as early as the 1970's to overcome the oil crisis, and solar PV energy was one of the sustainable substitutes that could increase national energy security. Based on this innovation system, Germany has played a significant role in the development of the global solar PV market, being one of the

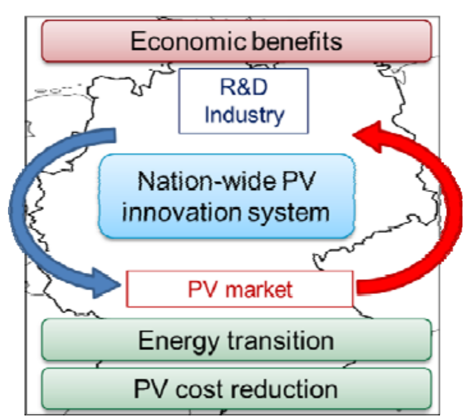

Figure 1: Nation-wide innovation mechanisms

pioneering countries over the past few decades. The country followed the classic linear model of innovation from focusing on early R&D investment and then expanding to demonstration and commercialization. Since then, the country's development path has focused on both supply (R&D, industry) and the use of solar PV cells (installations). The German market demonstrated high growth as a result of the synergy between the successful technology-push and the market-pull policies (FIT)

However, PV globalization has changed this mechanism. The nationwide system to create the virtuous circle of innovation in the PV sector has been broken with the arrival of cheap Chinese products in the global market.[1] From the mid-2000's, however, the increase in demand in line with policy supports (FIT) in Europe has attracted Chinese players into the PV manufacturing market. Chinese production soared in a short time mainly supported by export-oriented political supports (i.e., easy access to capital) and managed to quickly reduce the cost based on the GW-scale production capacity. China's rapid market expansion without domestic market development brought unexpected results, with an oversupply of PV products and fierce price competition which destabilized the PV market [4]. Many PV firms in the world have since gone bankrupt [5]. For example, the German industry has declined accounting for only 2% of world production (c.f., around 20% in 2006). Moreover, the PV sector encountered long-lasting trade disputes between major countries.

This PV industry crisis increased difficulties for countries aspiring to implement green growth policies with the combined policy objectives of energy transition and economic growth through PV growth (e.g., in Germany).

The oversupply issue has remained unsolved until now. For example, the top 10-module suppliers (30% of the global production capacity) can almost meet the world's PV demand (~ 70GW) in 2016[6]. The principle of the 'virtuous circle' of Watanabe [1] can be valid on condition that the national policy is sufficiently ambitious and stable based on the long-term. The nation-wide approach to create market demand is somehow limited to respond to the globalized PV industry. The national PV installations are usually insufficient to feed the GW-scale supply volumes that are required to gain price competitiveness [7]. Therefore, new solutions for the currently unbalanced PV market should be sought in the international arena.

In this regard, this study focuses on the unexplored potential of the PV market in new energy poverty regions. It should be noted that over 1.3 billion people worldwide live a daily life without access to electricity even though energy service is a crucial element for modern society and human well-being. They reside mostly in the rural area in sub-Saharan African or developing Asia and these regions have good solar resources. However, they easily use diesel generators or traditional biomass to supply energies despite the high operating cost or negative impact on the environment or health.

Methodologies and data

This study aims to analyze to what extent solar energy is an interesting energy option in these regions. We will cover the subject from both the supply-side (industry) and the demand-side (energy transition) perspectives to present a macroscopic vision of energy transition on an international scale. According to the World Bank, energy access problems are concentrated in Africa and Southeast Asia. Interestingly, however, there are also significant solar energy resources in these regions. Our analysis is thus based on data concerning 49 countries in energy poverty regions with good solar resources, including the least developed countries in Africa, Southeast Asia, India and Bangladesh. They represent 1.06 billion people.

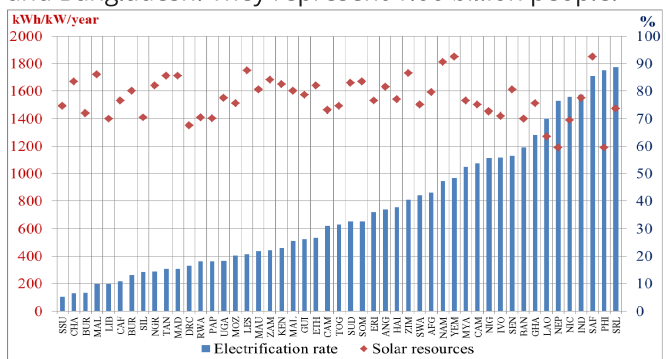

Figure 2: Electrification rate [9] and PV resources by country [10]

Our selection includes several major countries with a low energy trilemma index; 23 countries are ranked in the last 50 countries and 20 countries are unranked [8]. The average potential PV power output is 1548 kWh/kWp/year (about 50% higher than the average PV resources in Europe).

Our study aims to quantify the fact that the electricity demand in these areas can be supplied using the abundant solar energy resources. However, PV development in these regions is not without risk. Even though the risks differ according to each country, the financial risk is one of the great obstacles to developing PV markets in these areas. Institutional risks can also exist, e.g., a lack of standards or infrastructures. Therefore, it is hardly possible to supply electricity to all residents based on the grid-connection since it is a very expensive solution.[2] Diesel generators are the classical way of supplying power in these regions (substitute risks).[3] In this regard, as PV systems have the advantage of being able to provide decentralized power, the utilization of off-grid PV systems seems to be an appropriate solution in these regions.

In this regard, this study identifies the potential market size of the solar PV industry in new regions

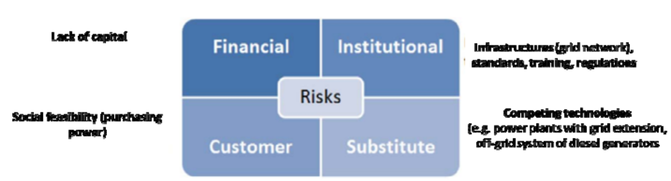

Figure 3: Risks analysis of PV development in new regions

based on combined PV systems with Li-ion batteries for residential applications. In order to define the system specifications, we have considered that those with no access to electricity would need the same amount of electricity as the average power consumed by the population with electricity. The calculated average is 922 kWh/year per capita in these countries[4]. Since the average potential PV power output in these countries is 1548 kWh/kWp/year, we concluded that a solar panel of 0.6 kWp/capita[5] would allow us to meet the electricity demand. We thus assumed the use of 2kWh[6] batteries coupled with the 0.6 kWp PV systems can store almost 80% of the average daily consumption.

Results and discussions

In this section, we describe the opportunities available for the world's energy transition by using solar PV systems in the selected countries. The maximum potential market size of solar PV industry is defined.

- **Potential market size of electrification:** we estimate that the total market size for full electrification in these regions is about 640 GWp (0.6 kWp x 1.06 billion people). This results in an electricity consumption of around 980 TWh/year (922 kWh/year x 1.06 billion people).

- **PV costs vs. diesel generators to meet the estimated demand**
  This section examines to what extent solar PV power is a more affordable energy option compared to diesel generators. We assumed that the diesel price would stay constant in the future so we could carry out a quick comparison. The fuel price is an important variable when defining the LCOE[7] of diesel generators. The LCOE of a diesel generator is c$ 29.7 / kWh to c$ 33.2 / kWh [9][8]. The LCOE of PV systems coupled with 2 kWh[9] batteries is calculated adjacent.
  Based on our calculation, it can be seen that electrification with the PV technology is less expensive than the power supply by diesel generators. In addition, even the combined PV systems with batteries are more economically feasible without jeopardizing the competitiveness of PV systems when the solar resource is over about 1550 kWh (24 of the 49 countries selected). Furthermore, if we include negative externalities in the energy system with respect to the generation of large quantities of CO_2 emissions, the real costs of diesel generators will increase.

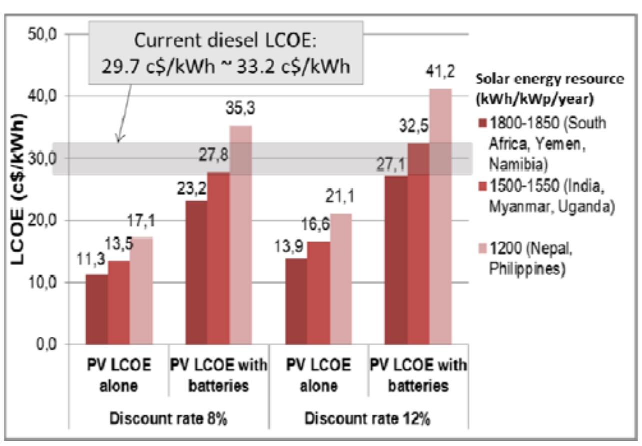

Figure 4: LCOE of PV systems coupled with 2 kWh batteries compared to the LCOE of a diesel generator

However, diesel generators require a low initial investment, but significant operating costs because of diesel consumption[10], while PV systems have a large initial investment cost but negligible operating costs (Table 1). Therefore, we can infer that residents use diesel generators because of their low initial investment costs despite their high fuel costs and negative impact on the environment

As defined, a total of 980 TWh/year is needed for full electrification in the 49 countries selected with an average consumption of 922 kWh/per capita/year. The CO_2 emissions will differ according to the energy technology employed. If we supply electricity with diesel generators, it will produce more than 1500 Mt CO_2 per year. This amount accounts for almost 5% of the current global emissions, i.e., 32.2 Gt CO_2/ year [10]. Therefore, we can conclude that PV systems provide a solution for electrification in a more eco-friendly way. About 1500 $MtCO_2$/year (1548 $MtCO_2$/year-49 $MtCO_2$/year) can be avoided compared with the use of diesel generators. In addition, PV systems can replace the traditional biomass for cooking and heating in the less developed countries, which poses hazards to human health and the environment [11,12]. However, the diffusion of PV systems cannot be created without international political reactions because of financing issues in these regions.

diesel generators	PV systems with batteries
US$ ~ 300 (upfront) + > US$ ~ 250/ year (fuel)	US$ ~ 2100 (upfront)

Table 1: investment comparison

New way of thinking: international -wide mechanisms for low-carbon energy transition

The proposed opportunities to include new frontiers for the global PV market growth would provide the PV industry with new outlets for the current oversupply of PV products. This approach expands the scope of the global PV market within the international context so as to solve current PV industry anxiety. The financial situation of PV firms is not the same as before the PV industry crisis led to fierce competition. The investment of an individual PV firm includes high risks. Players can consider joint investment strategy (e.g. strategic alliance, joint venture) to develop new markets together; the total costs can be shared with fewer business risks. Players can react differently to the markets to avoid reproducing the same situation as during the PV industry crisis. Furthermore, new regions could also benefit from the sustainable energy supply system for their socio-economic development.

In particular, this solution provides an interesting option to address the problem of world energy poverty. It would increase the world's electrification rate and eventually have a positive impact on global economic growth.

In this context, as shown in Figure 5 a 'virtuous circle' could be created in the PV sector on a global scale. The nation-wide perspective on energy transition can be expanded to include international markets so that energy transition on an international scale can lead to synergies between the supply-side (industry) and the demand-side (energy transition) in order to reduce global solar PV costs. As previously explained, the existing PV market growth is limited compared to the global PV supply capacity. By broadening the scope of the potential PV market to cover the entire international arena, the investment within an open economy to increase the foreign demand of PV installations will be partially returned to the participating countries. In addition, future PV costs would be reduced thanks to the enlarged market size and experience. It is important to note that the enhanced competitiveness of PV power would eventually contribute to future national-based installations in all relevant countries with reduced PV costs. In this context, based on our model, the energy transition can be implemented within an international context.

Solar projects in new regions can address several global issues such as energy poverty, climate change and PV market issues. However, the inhabitants in these regions are most likely to be reluctant to invest in PV systems due to high upfront capital costs. Common cooperative efforts to develop these regions are needed (financing, best practice sharing, standardization, etc.).

Global collaborative actions that widen the energy security frontier based on abundant PV resources are highly recommended for not only environmental sustainability, but also global economic benefits. Therefore, all stakeholders would benefit from the approach that encompasses new regions with improved energy access regardless of the political objective (industry or energy transition). As a result, a 'virtuous circle' in the PV sector can be produced on an international scale.

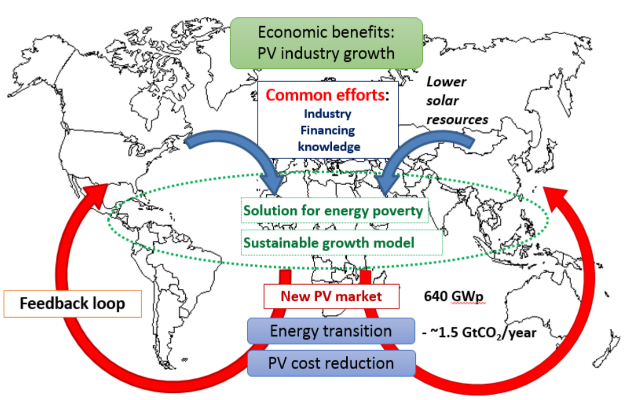

Figure 5: Global PV virtuous circle

Footnotes

[1] In addition, the market leader's production of PV modules was almost equivalent to the European PV demand in 2016 (~ 7 GW in 2016).

[2] Many countries among the selected countries have large territories to cover, which lead to high grid extension costs.

[3] Customers also tend to prefer to employ an energy option that generates the lowest initial investment cost (customer risks).

[4] To define a realistic power consumption pattern, we need to determine the average power consumption per capita with electricity access in these countries. We divided the power consumption per capita by the electrification rate based on the country data available from the World Bank

[5] 922 kWh / year per capita /1548 kWh / kWp / year = 0.6 kWp/capita

[6] A daily consumption of ~2.5 kWh/ day is necessary (~2.5 =922 kWh / 365)

[7] The levelised cost of electricity: LCOE of PV systems with batteries =

$$LCOE\ of\ PV\ systems\ with\ batteries = LCOE_{PV} + LCOE_{battery} = \frac{\sum_{t=1}^{n} \frac{I_{PV}^{t} + O\&M_{PV}^{t}}{(1+r)^{t}}}{\sum_{t=1}^{n} \frac{E_{PV}^{t}}{(1+r)^{t}}} + \frac{\sum_{t=1}^{n} \frac{I_{battery}^{t}}{(1+r)^{t}}}{\sum_{t=1}^{n} \frac{E_{PV}^{t}}{(1+r)^{t}}}$$

[8] With a diesel price at 1.057 $/L

[9] Our calculation was based on the battery price of 500$/kWh[10][8.]

[10] Diesel price between 1.5 and 4 $/gallon according to the supply chain.

References

[1] Watanabe C., Wakabayashi K., Miyazawa T. Industrial dynamism and the creation of a "virtuous cycle" between R&D, market growth and price reduction: The case of photovoltaic power generation (PV) development in Japan. Technovation 2000; 20(6): 299-312.

[2] Yu H.J.J., Popiolek N., Geoffron, P. Solar photovoltaic energy policy and globalization: a multi-perspective approach with case studies of Germany, Japan, and China. Progress in Photovoltaics: Research and Applications 2014.

[3] IEA PVPS 2011 to 2013. Trends in photovoltaic applications

[4] Bloomberg new energy finance 2014. Solar insight - research note: PV production in 2013: an all-Asian affair

[5] European Commission 2015. Perspectives on future large-scale manufacturing of PV in Europe. JRC science and policy report

[6] World Energy Council. Energy trilemma index. [Online] Available at: http://www.worldenergy.org/data/trilemma-index [Accessed 15 May 2016]

[7] The World Bank. Access to electricity (% of population) [Online] Available at: http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS/countries?display=default [Accessed 18 May 2016]

[8] JRC European Commission. Photovoltaic Geographical Information System - Interactive Maps. [Online] Available at: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=europe [Accessed 10 Apr. 2015]

[9] Lazard. Lazard's levelized cost of energy analysis - Version 8; 2014.

[10] IEA 2015. Data from world CO2 emissions from fuel combustion - Recent trends in world CO2 emissions from fuel combustion

[11] MacCarty N., Ogle D., Still D., Bond T., Roden C. A laboratory comparison of the global warming impact of five major types of biomass cooking stoves. Energy for sustainable development 2008; 12(2): 56-65.

[12] Barnes D.F., Kumar P., Openshaw K. Cleaner Hearths, Better Homes; 2012.