# A FRAMEWORK MODEL FOR POST-SUBSIDY PV MARKET FORECAST

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**ABSTRACT**

The paper addresses the key question of assessing potential future PV development in every country. Especially after the phase out or in the absence of any financial policy support, subsidies or political barriers influencing PV development, a sustainable and thus highly predictable PV development is assumed. The method proposed in this paper is of major interest to anticipate the potential development of PV in emerging markets where, the absence of any significant financial support scheme has usually prevented the uptake of policy driven (and non-competitive based) PV market. Therefore, in most of these markets, PV has been installed solely due to its intrinsic competitiveness in comparison to other power generation technologies.

The method thus assumes that PV is transitioning towards a post-subsidy era and that the long-term PV development in any given country will be driven by its true competitiveness only. The paper presents an overview of PV development scenarios in 21 countries of which 4 highly contrasted examples are analysed in more details and will be a basis for evaluating a closer analysis of all other PV markets future developments.

**Keywords**

Emerging Markets, Logistic Growth Curve, PV Market Development, PV Penetration, Long-Term Scenario

## 1 MOTIVATION

PV markets have historically started to develop due to the influence of highly favourable policy incentives schemes intended to develop the renewable energy markets.

Representing a fast growing market estimated to exceed 60 GW this year [1], the PV market is currently scrutinized by a number of market research companies, with many reports being periodically published on the anticipated short-term PV market development [1].

Most of available market analyses however result from a similar methodological approach that typically consists of an anticipation of near future market behaviours based on the analysis of historical market developments and of the anticipated short term policy evolution, in order to derive the level of PV attractiveness and the likely short term development of the market.

Such method is by essence an incremental approach, i.e. it is based on the analysis of the current market situation and of short-term observable market drivers.

If such an approach might prove useful for short-term forecasts in already existing markets, it fundamentally fails to integrate the true long-term attractiveness of PV driven by its intrinsic competitiveness. Thus, the high long-term penetration potential of PV in the electricity system is often not considered. Moreover, this traditional approach is continuously applied to well established markets and not for countries without support policy and/or where no mature PV market exists.

PV is expected to become one of the least cost generation technologies in the future [2]. Therefore, a reliable long term projection of competitiveness driven PV market development is expected to be an essential decision-making tool for any stakeholder involved in defining long term energy strategy, regulatory framework or market development.

This paper describes the framework of a unique approach based on an analysis of the PV competitive long-term penetration potential in the electricity system of any given country. The development of cumulative installed PV capacities is calculated backwards until the year 2000, from which annual market installations are derived. This method proves to be particularly reliable and useful in countries where no significant PV market exists or where the instability and/or phase out of policy support makes any market development forecast difficult to ascertain.

## 2 METHODOLOGY

### 2.1 APPROACH

The method proposes, for any given country, to build a PV capacity development curve backwards from the long term PV penetration, by using a traditional logistic growth curve - that generally reflects the way markets tend to develop for an independent and competitive technology – by enforcing a number of constraints, as shown in Figure 1. To draw the curve, the calculated long-term penetration of PV is calculated for defining the long-term PV capacity, and historical data is used, when available for the short term.

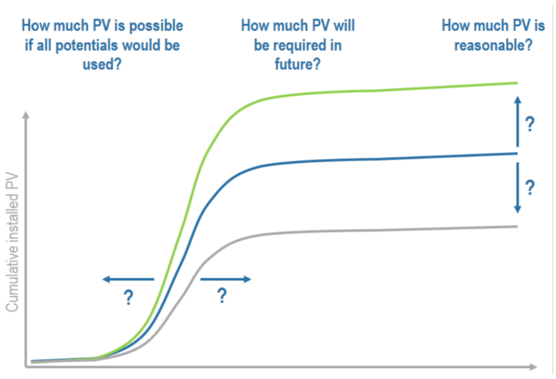


**Figure 1**: Schema of PV market development curves determined by external factors such as, available potential and long-term demand.

The 2050 long-term perspective in this paper assumes that under the only effect of its intrinsic competitiveness to other power generation, PV penetration in any given country will grow until it reaches a natural maximum, determined by several country dependent factors, and constrained by an absolute physical limitation resulting from grid constraints, the local attractiveness of other competitive energy resources and the need for generation continuity and flexibility.
To give a long-term perspective, 2050 has been chosen as it is widely used by official bodies and agencies as political and scientific milestone, when it comes to climate change (e.g. IPPC, ref [3]) and energy forecast (e.g. IEA, ref [4]) and further gives a well sized time frame of roughly 35 years after PV globally becoming one of the most attractive energy source.

## 2.2 HISTORICAL INSTALLATION DATA

Historical PV installation data for the years 2009 – 2014 for 190 countries provided by previous publications [5] has been utilized. Sources besides an international customs database, monitored by the 'Market Analysis and Research' section of the International Trade Centre, - an agency of UN's World Trade Organization - include IRENA, International Energy Agency Photovoltaic Power Systems Programme (IEA PVPS), journal du photovoltaique, the European Commission, Hanwha Q CELLS Market Intelligence as well as other public resources [6 – 13].

## 2.3 LONG-TERM PV POTENTIAL

To assess the long-term potential target of PV capacity for all countries, the methodology described in Figure 2 has been applied to determine first the level of power demand by 2050 within each country. The power demand forecast by country is derived from the IEA 2DS HIREN scenario [4]. The IEA 2DS HIREN scenario provides *gross electricity generation* forecasts in 2050. However, it only provides figures for a few countries, as well as for a number of cluster of nations. In order to derive country specific data, it has been assumed that a certain convergence of development levels and living standards would occur within each group of developed and developing countries, and that all countries within a specific cluster would reach a similar level of development by 2050, materialized by a comparable *gross electricity generation* per capita.
The *gross electricity generation* per country is then calculated on basis of the IEA 2DS HIREN data provided at cluster level and on the 2050 forecasted population of each country within the cluster, using the official population forecast from the World Bank [3].

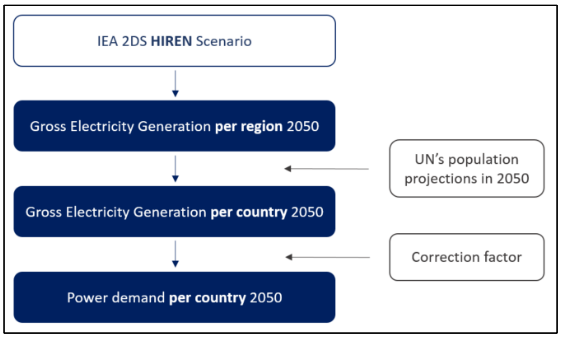


**Figure 2:** Methodology scheme to compute long-term power demand [3, 4].

Finally, the power demand is derived from the *gross electricity generation* using an efficiency factor representing the efficiency of power transport and distribution as a function of the development level of the country. The methodology provided in Figure 3 will assume two base scenarios for 2050, the 'HIGH scenario' and the 'LOW scenario', corresponding respectively to the assumed best and worst-case scenarios for PV penetration in 2050.

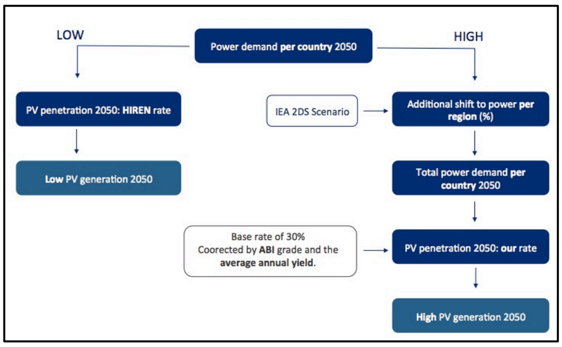


**Figure 3:** Development of LOW and HIGH 2050 scenarios based on differing assumptions regarding PV penetration in 2050.

To calculate both scenarios, PV capacity is directly derived from the calculated country specific power demand and the penetration rate provided by country and/or by cluster in the IEA 2DS HIREN scenario. In the original IEA scenario, PV should cover 16% of the global demand in 2050, according to varying penetration rates by region and/or by country. Due to the expected competitiveness of PV this scenario is assumed to be the 'LOW scenario' [4]. The 'HIGH scenario' is equally derived from the IEA 2DS HIREN scenario by adding two more aggressive assumptions.

First, it is assumed that the shift to power occurring by 2050 due to increasing shares of electric vehicles, electric heating and power-to-X applications will be significantly higher than the one expressed in the original IEA 2DS HIREN reference scenario. Electricity from Renewables is expected to outcompete other energy sources like oil and gas [2]. The 'HIGH scenario', thus assumes that countries will shift an additional 50%, 80% and 50% of their oil, coal and gas consumption to power respectively thereby significantly increasing the 2050 projected power demand compared to the 'LOW scenario'. These shifts to power were calculated considering average efficiency rates of 30% for oil, 40% for coal and 50% for gas technologies. Resulting increases in power demand vary significantly from country to by country.

Furthermore, the 'HIGH scenario' assumes a much higher penetration rate of PV of 30% on average according to factors representing:

- The general attractiveness of the country for PV investment (*Aggregate Business Index),*
- The general attractiveness of PV for the country.

For the first factor an *Aggregate Business Index (ABI)* is calculated as a weighted average of six indicators, extracted from the *Worldwide Governance Indicators (WGI)*, published by the World Bank [14]. These factors are listed in Figure 4.

| World Governance Indicators |
|---|
| 1. - Voice & Accountability |
| 2. - Political Stability & No Violence |
| 3. - Government Effectiveness |
| 4. - Regulatory Quality |
| 5. - Control of Corruption |
| 6. - Rule of Law |

**Figure 4** : Overview of Worldwide Governance Indicators (WGI) used in the ABI calculation [14].

The level of ABI calculated for each country is used to adjust the base penetration rate by a correction factor representing the investment climate dependency on the governance quality and stability within a country, as shown in Figure 5.

| ABI grade | Impact on PV penetration rate |
|---|---|
| A | +10% |
| B | = |
| C | -10% |
| D | -25% |
| E | -50% |

**Figure 5:** Aggregate Business Index (ABI) impact on PV penetration rates based on Worldwide Governance Indicators (WGI), published by the World Bank [14].

Additionally, the PV attractiveness for a country has been considered dependent on the solar irradiation level. The adjustment factors used by level of PV yield are shown in Figure 6.

| Yield (kWh/kWp) | Impact on PV penetration rate |
|---|---|
| 800 - 1200 | -20% |
| 1200 - 1500 | = |
| 1500 - 1700 | +20% |
| >1700 | +40% |

**Figure 6:** Impact of different yield impact on PV penetration rates in the year 2050.

Applying these correction factors to the base penetration of 30%, for each country, provides an estimated natural long-term penetration rate for PV in that country in the 'HIGH scenario'. The final PV penetrations rate in our 'HIGH scenario' range from 15% to 45%, the latter being considered as a physical limitation.

## 2.4 LOGISTIC GROWTH-FUNCTION

With the 2050 PV penetration goal calculated for each country and both scenarios the projected PV development curves have been plotted. A long-term growth can be described well by applying a logistic growth function in

Equation 1 [2].

$$f(t) = A + \frac{K - A}{(1 + Qe^{-B\cdot(t-M)})^{1/v}}$$

**Equation 1:** Logistic growth function in generalized form. Abbreviations: time (*t*), lower asymptote (*A*), upper asymptote (*K*), growth rate (*B*), parameter affecting near which asymptote maximum growth occurs (*v*), scaling parameter depending on f(0) (*Q*) and time of maximum growth (*M*). This growth function is used as a methodological tool to describe the long-term growth assumed for 'LOW and HIGH scenarios' in section 2.

The behaviour of the calculated logistic-growth curve was set to follow closely the historical PV development till 2014. A gap of ± 3% tolerance versus actual cumulated capacity was allowed in comparison to the 2014 cumulated installed capacity. The further progress of the curve towards 2050 was provided by the maximum PV capacity described in both the 'LOW and HIGH scenarios' for each country in combination with results on Residential Grid-Parity, Industrial Grid-Parity and Fuel-Parity from previous publications [15]. Without subsidy scheme, any type of parity, but Grid-Parity especially, provides the economic basis for the PV market.
This however does not automatically translate into spontaneous market growth. All market actors have to be aware of the opportunities PV represents and experience has to be developed on PV components, systems, installation and financing options. It is assumed that the lower a country ranks according to the Worldwide Governance Indicators [14], the higher are transaction costs in this market. A lower score corresponds to a reaction time of several years before PV is starting to become a major energy source in a country, and high installation rates are achieved. Thus as a matter of example, a reaction time of 4 years has been considered for developed countries like Sweden or Switzerland whereas countries such as the Democratic Republic of Congo or Nigeria are expected to need some 8 years before PV reaches the highest installation rates.
In several countries, sudden change of policy support has strongly impacted annual installation rates, such as in Germany or in the UK, and could even bring markets to a standstill [5], in countries such as Spain or Greece. Therefore, markets with an active policy support program have to be carefully extrapolated to account for the market development, which includes both policy driven installations, as well as installations resulting from emerging competitiveness of PV.

## 3 CASE STUDIES

For the purpose of this paper, 21 countries have been analyzed, which were chosen to be effectively representative of the majority of nations worldwide. The list has been formed by choosing a diverse mix of developed and emerging markets, island and continental countries, as well as nations with an established or without a renewable subsidy program. Table 1 shows the 21 countries and the respective cumulated maximum PV capacities for both the 'HIGH and LOW scenarios.'

In order to give an overview on a variety of countries and keeping in mind the ambitions of this paper, the case studies will focus on the HIGH scenario of the selected countries.

| Country | Cumulated PV Capacity in 2050 | |
|---|---|---|
| | Scenario - High | Scenario - Low |
| | [MWp] | [MWp] |
| Bolivia | 14.698 | 6.859 |
| Congo DR | 17.115 | 11.690 |
| Fiji | 313 | 112 |
| Ghana | 7.880 | 2.990 |
| Ireland | 14.118 | 3.810 |
| Kazakhstan | 18.493 | 3.818 |
| South Korea | 147.818 | 49.542 |
| Malta | 883 | 116 |
| New Zealand | 10.720 | 2.367 |
| Dominican Rep. | 10.584 | 4.199 |
| Nicaragua | 5.374 | 2.468 |
| Nigeria | 45.671 | 22.282 |
| Pakistan | 158.871 | 53.675 |
| Poland | 61.311 | 18.617 |
| Portugal | 16.711 | 3.383 |
| Russia | 201.038 | 12.205 |
| Egypt | 154.900 | 76.452 |
| Peru | 45.356 | 18.280 |
| Spain | 81.536 | 16.505 |
| Sweden | 71.008 | 0 |
| Switzerland | 14.578 | 4.664 |

**Table 1:** List of 21 countries, representative of the majority of nations worldwide and their respective forecasted 2050 maximum cumulated PV installations in the 'HIGH and LOW scenario.'

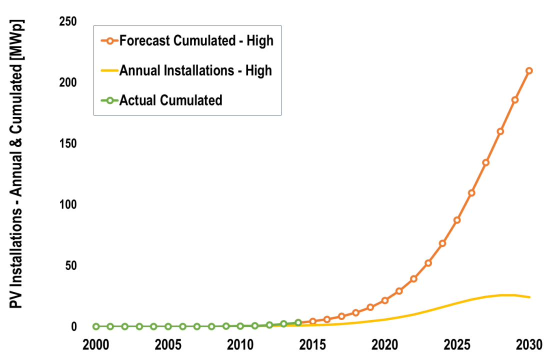


**Figure 7:** Results for the island nation of Fiji in the 'HIGH scenario', which will reach 313 MWp cumulated in 2050. In 2014, the capacity stood at 3.2 MWp. The orange curve shows the forecasted cumulative PV installation, while the yellow line states projections for annual PV added.

For the countries in Figure 7 – 10 the method described in section 2 provides excellent results and depicts the historical development with high accuracy. Depending on the individual characteristics of the country, PV market growth may start earlier or later. Figure 7 shows the projected PV development in the island country of Fiji. Typically, island nations are characterized by high energy prices due to imports of fossil fuel, enabling PV to be competitive earlier than in countries that claim relevant fossil fuel resources. By end of 2014 Fiji claimed 3.2 MWp PV installed. The projection expects some 313 MWp of PV power potential for Fiji to be reached by the year 2050. Following the methodology proposed in this paper that is purely based on PV competitiveness versus conventional power generation, PV is expected to take off in the coming years and reach some 21.5 MWp of cumulative PV installations by 2020 and 210 MWp by end of 2030. Highest annual installations are expected to take place roughly around 2025. For the end of 2015 this methodology projected 4.4 MWp installed cumulatively. Actual numbers reached by end of 2015 show a very close match with 4.6 MWp installed. For the end of 2016 it is expected that 6.0 MWp will be installed cumulatively.

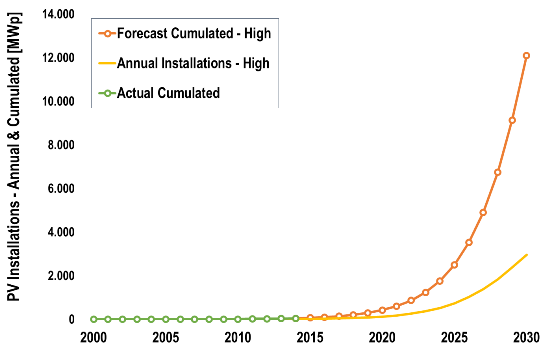


**Figure 8:** Results for the African nation of Nigeria with 175 million inhabitants in the 'HIGH scenario', which is expected to reach 45,700 MWp cumulative PV in 2050. In 2014, the installed capacity amounted to 45.6 MWp. The orange curve shows the forecasted cumulative PV installation, while the yellow line states projections for annual PV added.

Nigeria, shown in Figure 8, suffers as a developing country from high market transaction costs and therefore significant PV deployment may only start beyond 2020. There was 45.6 MWp installed by end of 2014, that has been expected to grow to 68.4 MWp by end of 2015, according to the present methodology. The real numbers for 2015 show that 68.1 MWp have been installed cumulatively by end of 2015, which matches perfectly the projected amounts [5]. The highest annual installations of 4,150 MWp are expected to be reached in 2033, with already high figures of several GWp of annual installations expected during the 2020s. This demand will be enhanced by drastic growth of power demand going along with rapid GDP growth and the attractiveness of PV compared to the opportunity cost of fossil fuel resources, if these are not exported to global markets. With 175 million inhabitants in 2015, the country could reach a cumulated PV capacity of 45,700 MWp by 2050.

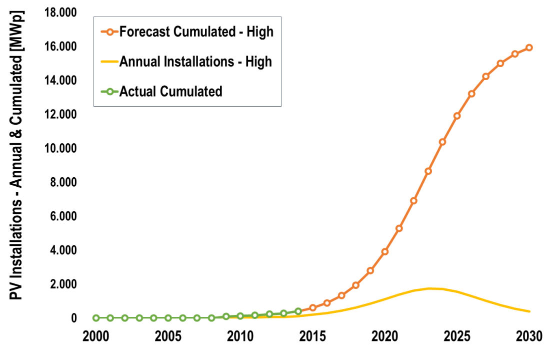


**Figure 9:** Results for the developed nation of Portugal with 10.5 million inhabitants in the 'HIGH scenario', which will reach 16,700 MWp cumulated in 2050. In 2014, the capacity stood at 402 MWp. The orange curve shows the forecasted cumulative PV installation, while the yellow line states projections for annual PV added.

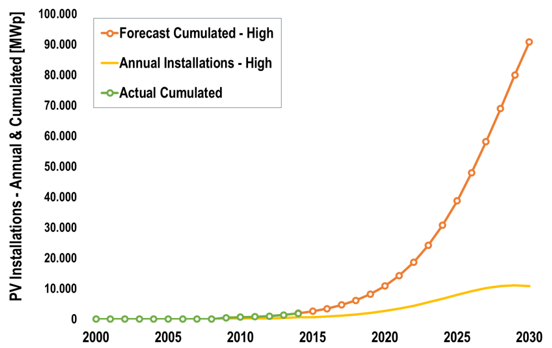


**Figure 10:** Results for the developed nation of South Korea ranking 11$^{th}$ regarding GDP in the 'HIGH scenario', which could reach 147,700 MWp, cumulated in 2050. In 2014, the capacity stood at 1,906 MWp. The orange curve shows the forecasted cumulative PV installation, while the yellow line states projections for annual PV added.

Within the category of developed countries, actual installations in Portugal and South Korea, shown in Figure 9 and 10, seem to follow the logistic growth curve quite closely. Furthermore, PV development in these countries has been very stable in recent years and thus very predictable, showing constant growth rates of about 30% and 40% respectively [5]. With high solar irradiations and relatively high conventional grid power prices solar power is today an attractive cost option ranging from the residential to the utility scale segments [15]. This leads to PV installations expected to take off in near future to reach 3,900 MWp of cumulative installed solar capacity by end of 2020, while 461 MWp have been installed till the end of 2015. It is estimated that Portugal would reach 16,700 MWp of PV installed by 2050 of which the majority will be installed during the early 2020s in a relatively steep growth rate. In comparison South Korea that shows a rather steep but flatter growth curve should reach about 10,800 MWp by 2020 with an overall 2050 target of 147,700 MWp installed cumulatively.

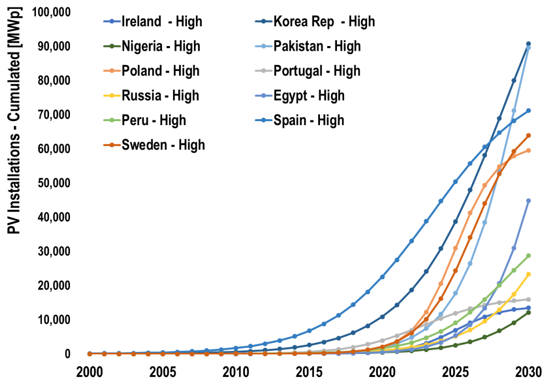


**Figure 11:** Overview of projected PV development for countries in this study with expected 2030 PV installations above 12,000 MWp. The graphs refer to cumulative installed PV capacity in each country per respective year.

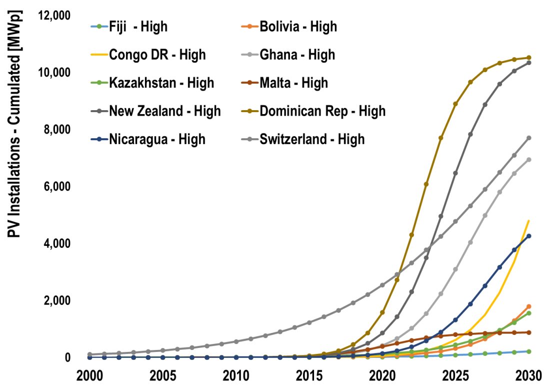


**Figure 12:** Overview of projected PV development for countries in this study with expected 2030 PV installations below 12,000 MWp. The graphs refer to cumulative installed PV capacity in each country per respective year.

Figure 11 and 12, show that Pakistan and South Korea are the markets, among the 21 countries of this study, that are expected to show highest PV cumulative installations by end of 2030 with an 89,000 MWp and 90,000 MWp respectively. Even though both countries are forecasted to reach comparable installation numbers by 2030, the way to achieve this projected point shows some different development. Whereas the South Korean market will, with a flatter development curve, show relevant annual installations already before 2020, the Pakistan market should be delayed in its development, even having already installed some 600 MWp in 2015 [5]. A main reason for this delay can be seen in the negative influence of business attractiveness factors that due to high level of corruption rank much lower than South Korean ones. Figure 12 shows that markets such as the Dominican Republic and New Zealand should develop very quickly their PV potentials during the early 2020s, and will already reach a slight flattening before 2030. This translates to only low figures of PV additions after 2030, with an installation focus of replacing and upgrading existing PV power plants. The same is valid for Malta, which, like the Dominican Republic and New Zealand, is and island country. This shows PV true and intrinsic competitiveness in comparison to high conventional energy costs, especially on remote islands that usually have to import high shares of their energy needs.

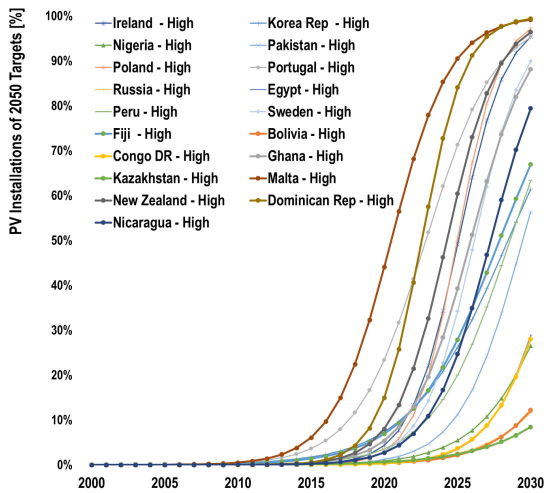


**Figure 13:** Projected PV installation of the 2050 PV targets identified per each year.

As already stated in Figure 11 and Figure 12, some countries show earlier or delayed takeoffs of their respective PV developments. As result of this competitiveness-based methodology, such delays or early starts give a close insight of the PV attractiveness versus the cost of conventional power generation systems. As an early starter, Malta has already reached 6%, and will reach 99% of its 2050 expected PV capacity already in 2030. This immediately results from PV power being less expensive than the conventional diesel power generation on the island – even though a new, however under-sized, grid connection to Sicily has been inaugurated recently. Further early starters are New Zealand, the Dominican Republic, Fiji, Portugal that all are expected to implement relevant parts of their expected 2050 PV targets before 2025. On the other end, countries that claim high amounts of fossil fuels like Kazakhstan, will show delays in their PV developments with reaching by 2030only 8.5% of their 2050 target equivalent to 1,500 MWp.

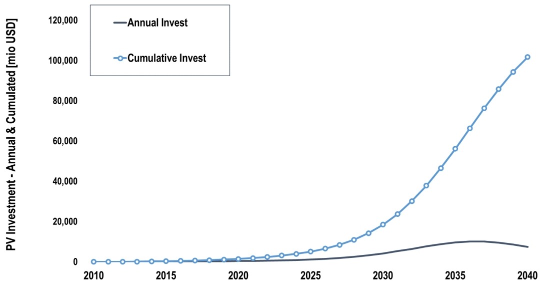


**Figure 14:** Projected PV investment in Russia until 2040 in million USD. The light blue graph refers to cumulative investments while the dark blue ones represents annual expected investments.

By combining the unique results of this methodology with data on historical data and future forecasts on PV system costs, an estimation of expected PV investments is possible. System costs are expected to decrease down to a global average of 1,200 USD/kWp by 2020, 714 USD/kWp by 2030 and 580 USD/kWp by 2040 [15]. In the example of Russia given in Figure 14, 101 billion USD are expected to be invested into PV until 2040 enabling the installation of 154,000 MWp of PV in that period. Highest annual investments are expected for 2036 and 2037 with 10 billion USD per each year.

## 4 FURTHER DEVELOPMENTS

The approach presented in this paper is based on a robust methodological framework and proves to be highly effective in a variety of contrasted situations.

However, it is believed that further refinements could be brought by implementing additional differentiation to the countries belonging to the same cluster, which in this paper, have been considered as reaching the same development level, and thus the same energy intensity per capita by 2050.

Secondly, if the method provides useful information on the electrification level and the contribution of PV, it currently does not allow to be prescriptive on the type of electrification/PV deployment that will take place. Additional considerations on the existing electrical system technology and governance, on the core economical activities of the country (agricultural, industrial, mining, etc.) and on the level of centralization of the country would further be required in order to describe the natural electrification path in more details and distinguish central vs. community vs. individual electrification.

Finally, considering the very promising results delivered by this paper, that also draws from previous publications, the authors intend to release later this year a report extending and detailing this analysis to all countries worldwide [2].

## 5 CONCLUSIONS

The paper shows both the applicability and the robustness of the method that constitutes a highly original approach to forecasting sustainable mid-term and long-term PV development, based on its sole economic competitiveness in any given country and further assuming all policy support will progressively phase out in the coming years. It provides as such a reliable instrument for policy makers in emerging countries to build advanced understanding of the most straightforward and economical path for electrification of their country.

Comparing expected PV market development calculated with the methodology proposed in this paper, before official installation data for 2015 were available, shows that for the majority of countries, actual 2015 cumulative installed PV capacity data match perfectly to the projected figures. As an example, this methodology projected some 53.6 MWp and 68.4 MWp installed by end of 2015 in Malta and Nigeria respectively. Latest installation data show a close match of 55.6 MWp and 68.1 MWp installed in these countries by end of 2015 in real [5]. This proves the great accuracy and suitability of this methodology for the prediction of mid-term and long-term PV development, especially for sustainable non-policy driven PV markets.

The paper will be used as the methodological framework for the development of an extensive study on emerging markets undertaken by the authors and planned to be released in Q4 2016.

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