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Article

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International Journal of Energy Economics and Policy

Reference: Achmetžanov, Bura Achmetžanovič/Tazhibekova, Kashamida et. al. (2018). Expanded implementation of solar photovoltaics : forecasting and risk assessment. In: International Journal of Energy Economics and Policy 8 (5), S. 113 - 118.

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2018, 8(5), 113-118.

Expanded Implementation of Solar Photovoltaics: Forecasting and Risk Assessment

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ABSTRACT

This research is a forecast of solar photovoltaics (PV) implementation made for a period through to 2030. The leading factors of PV development that were included into the forecast model are the price for PV modules, the efficiency of silicon solar panels, the price of lithium-ion batteries, the price of lithium and the silicon PV module manufacture. The model is based on the calculations made for the coefficients of correlation between the installed capacity and economic factors. The ARIMA forecasting method was applied to generate forecasts for each factor and installed capacity riding on specific factor's back. The calculated coefficients show a strong correlation between the installed capacity and the above listed factors. According to the generated forecasts, the efficiency factor will reach an abstract limit of 30% by 2030. Investments in PV will increase up to 70%; this is 10% higher than current level.

Keywords: Photovoltaics, Forecasting, Risk Assessment of Photovoltaics Implementation, Photovoltaics Power, Correlation Coefficients
JEL Classifications: A11, B41, C01

1. INTRODUCTION

Solar photovoltaics (PV) is one of the most popular sources of renewable energy in the world (Jean et al., 2015). The question has recently arisen about the state strategies for transition to solar power driven by the policy of saving common fuels (natural gas and oil) and reducing the greenhouse gas emissions (Jean et al., 2015; Arnold et al., 2015; Sagani et al., 2017). The number of investors in renewable energy projects is greater and greater by the day (Breyer et al., 2010). According to the forecast made by the Fraunhofer-Institut für Solare Energiesysteme ISE, PV development is of a non-linear kind, so some big corporations recognize their inability to plan long-term investments (Tietjena et al., 2016). The investment environment for PV energy projects is a complex one with various types of risk factors, such as the value of primary raw materials, solar panel production, technological innovations, etc. and with complex relationships between these factors (Yildiz, 2014; McFarland, 2014; Pillai, 2015). PV development depends on the technology of PV module production. Despite the fact that there are several photoelectric materials, including *CdTe* (Crisp et al., 2017; Romeo et al., 2018), *CuInxGa1-xSe2* (Alamri and Alsadi, 2017), organic perovskites (Kim et al., 2017), polymers (Zhao et al., 2017) and plasmonic-enhanced solar cells based on plasma resonance (Gao et al., 2017; Dhonde et al., 2017), silicon remains at the list top.

The main advantages of *Si* are its infinite reserves (infinite because it is extracted from quartz or sand) (Green, 2000) and good physical characteristics (lifespan, series resistance and optical properties) (Yoshikawa et al., 2017). Some believe that silicon technology will lead the industry to less costly large-scale power production via reduction in the value of solar modules (Breyer et al., 2010; Green et al., 2015; Pillai, 2015; Green, 2016). The economic analysis of small rooftop power systems based on 2-10-kW solar modules shows their economic profitability, but the increase in power prices is crucial for the development of small-scale PV systems in the country (Sagani et al., 2017; Sandor et al., 2018). Improving the efficiency of energy conversion was originally the goal of major research and development projects in the field of PV. The increase in the efficiency of a silicon battery (>30%) and its approximation to an ideal value (Yoshikawa et al., 2017) are achievable by improving the technology, but the technology itself must be cost efficient (Inman et al., 2013; Lee and Ebong, 2016). The growth of fresh power capacities will be driven by the rural areas or isolated settlements (Giddings and Underwood, 2007; Lahiri et al., 2018) because the climatic conditions there (openness to solar radiation, sunny weather, etc.) are suitable for the purpose. Concerning the establishment of remote off-grid solar stations, batteries automatically become an integral part of the future (Ahmadi et al., 2017). *Tesla* and other major battery manufacturers perceive the energy-saving projects as the most attractive part of the power market. Tesla delivers the built-in rechargeable battery pack *Powerwall* designed to fit solar panels produced by Tesla and other manufacturers (Blomgren, 2017). At this point, however, a number of problems arise, namely – battery production rates (Lahiri et al., 2018), outdated government regulation and insurance problems (Tietjena et al., 2016). Accordingly, these problems prompt the companies to take into account their abilities to maintain solar power plants.

The Fraunhofer-Institut für Solare Energiesysteme ISE (2018) does the PV forecasts and assess the risks of an investment project. The Monte Carlo Simulation (MCS) was applied to assess the risk of an investment project based on the lifespan of renewable energy technology (Arnold and Yildiz, 2015). This model allows the investors to assess the risk of the rate of return and the volatility of investment in infrastructure, to determine the effect of adjustments made and the stepwise project variations. In China, renewable energy consumption growth was analyzed using the Gray system theory and regressive analysis. Based on regression analysis, they considered factors that contributed to a decrease in the cost of solar panel production. As it was revealed, advanced industries supplying the solar panel production with raw materials and equipment are important factors when it comes to reducing the cost value of solar panels. The relationship between the renewable energy consumption and the economic growth in South Africa was studied as well. Speaking long term, appropriate and effective public policies are required on the background of sustained economic growth (Khobai and Le Roux, 2018).

Technological, market and political risks in the field of renewable energy sources were assessed using the system dynamics method (Liu and Zeng, 2017). As it was revealed, political risk is the main factor affecting investments at the beginning of the project development stage, although its effect is declining over time. The market risk introduces uncertainty that affects the investment in the project when the project is in the middle of development. Thus, there are a number of factors affecting the PV development. Each thereof becomes stronger by itself, but still has a significant effect on PV development. The issue of PV development forecast is considered through the lens of price of a technology, political and weather conditions. At the same time, risks associated with pure polysilicon production, with rates of battery production for energy independent solar modules, with investments in power plants, etc. are not taken into account, although they are things that have to be taken when generating a forecast.

The purpose of this research is to test the hypothesis put forward by a PV development forecast, made by the Fraunhofer Institute for Solar Energy Systems, ISE. Therefore, we tend to take into account all the bottlenecks, to assess their effect on market development in the past, to predict the future track of these factors, and to fit the forecast for PV industry development with the forecasts for all possible factors. An autoregressive integrated moving average (ARIMA) model as a statistical method for time series forecasting is often applied to analyze statistical data and forecast the economic indicators. However, its direct application in economic statistics will not factor in the internal drivers and headwinds. Therefore, it cannot generate a correct long-term forecast. Our approach is intended to eliminate these shortcomings and generate a weighted long-term forecast.

2. METHODOLOGY AND DATA

2.1. Model Specifications

This research is devoted to the cause-and-effect relationship between the installed PV capacity and the economic factors (Figure 1) that affect its development.

At the bottom of the forecasting model, there are coefficients of correlation between all the factors and the capacity. Correlation coefficients for the ordinal variables are represented by the Spearman's rank correlation coefficient (Spearman's rho) and the Kendall rank correlation coefficient (Kendall's tau), while the coefficients for the interval variables – by the Pearson product-moment correlation coefficient (PPMCC).

The value of selective PPMCC can be calculated by:

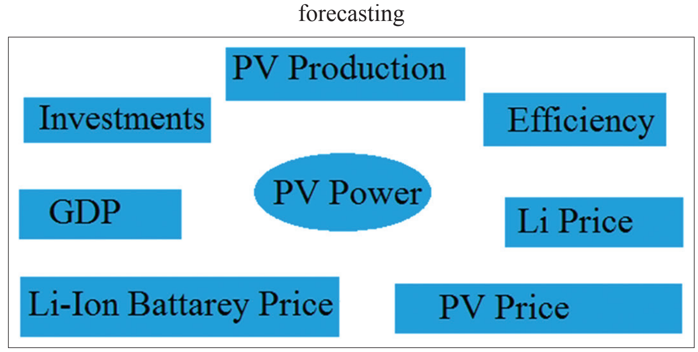
$$r_{xy} = \frac{\Sigma(d_x \times dy)}{\sqrt{(\Sigma d_x^2 \times \Sigma d_y^2}} \tag{1}$$

Where: d_x d_y – mean deviation of research variables.

Each factor's track was calculated using the ARIMA forecasting method in SPSS Statistics (Xiao et al., 2014).

Then, each forecast was approximated. The approximant was applied to find the coefficients of correlation between just the forecasts for economic factors and between them and the PV development forecasts. The correlation coefficients found gave rise to forecasting PV capacity improvement on the background of all factors.

Figure 1: Independent variables for photovoltaics development forecasting



2.2. Data Sources

The research was carried out with regard to time series data (prices of solar modules, efficiency of silicon solar panels, prices of lithium-ion batteries (LIBs), prices of lithium, silicon production) for 2000-2017. The forecast is based on statistical data available from the reports for the February 26, 2018 (Fraunhofer Institute for Solar Energy Systems, ISE with support of PSE Conferences & Consulting GmbH, Bloomberg GW, EPI, Metalery). The PV forecast is for the period through to 2030.

3. RESULTS

As the Fraunhofer Institute forecasted (Figure 2), PV will develop under a nonlinear law. There are three forecasts made – optimistic, real and pessimistic with a confidence interval of +_90 (Photovoltaics Report, 2018).

We have applied the ARIMA forecasting method to develop a forecast for PV development, which is somehow similar to the one that the Fraunhofer Institute has developed. The confidence interval of +_90 indicates that the forecast made by the Institute is not accurate. We do not know the details of the Fraunhofer Report, but we will attempt to make a forecast with regard to the complex system of interdependent economic processes.

We conducted an analysis and found out that there are strong correlations between those processes. Correlations between the power output and factors are in Table 1.

Table I shows that there is a strong correlation (0.677–0.97) between all the factors and the power output. PPMCC indicates that the strongest relationship is between the capacity and the price of Li, while the Spearman's and Kendall's coefficients indicate that the strongest relationship is with the prices of LIBs (negative strong correlation (−1)). This situation arisen due to a necessity to launch solar power stations in distant locations (Phillips and Dickie, 2015), and this requires LIBs, as they fit the autonomous power supply systems perfectly. There is also a strong correlation (0.92) between the capacities of solar cells and the gross domestic product (GDP), as PV development and GDP are sensitive to investment. Moreover, the global crisis will also hit the PV industry (Khobai and Le Roux, 2018). Over the past 18 years, the coefficient of regression between investments in PV and the GDP is 0.9236 (PPMCC). This indicates that they are highly interrelated. Figure 3 shows three time series – investment time series, GDP time series and a differentiated GDP time series. Figure 3 shows that the rates of curves are similar for all of cases; PV development depends on GDP per capita and on the investments in PV, so all the crisis disturbances in PV development coincide with the GDP crises (Figure 3) (Wüstenhagen and Menichetti, 2012).

The coefficients have different values because Spearman and Kendall did not impose a restriction on the type of basic data distribution, in fact – they [coefficients] are less sensitive to deviated variables. Based on data in Table 1, we can conclude that there is a strong dependence of the installed capacity of solar panels on all of the above listed factors. We will evaluate the installed capacity improvement with regard to this relationship.

The forecast for photovoltaic power output is in Figure 4. According to the optimistic forecast, the installed capacity will reach $2*10^{12}$ W by 2025, while the Fraunhofer forecast indicates that it will reach $4*10^{12}$ W.

Figure 2: Forecast developed by the Fraunhofer Institute (Photovoltaics Report, 2018)

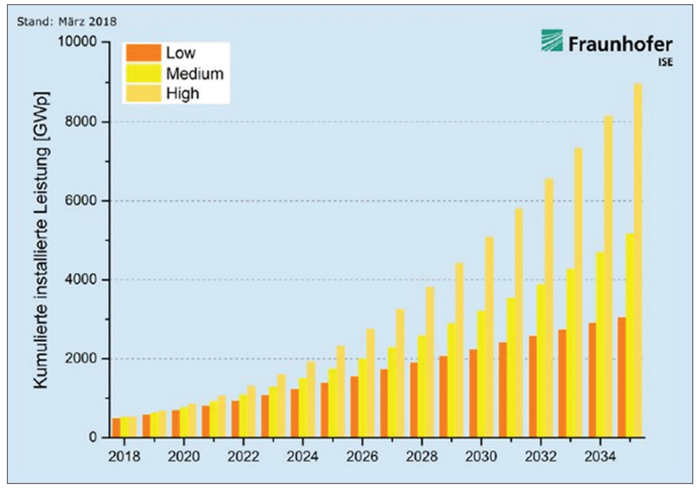


Figure 3: Gross domestic product (GDP) time series – differentiated GDP Time Series – investment time series

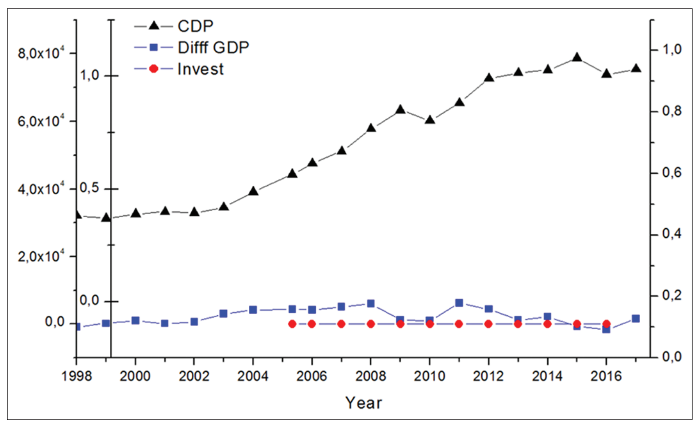


Figure 4: Installed photovoltaics capacity forecast: 1,2,3 lines – Fraunhofer Forecast

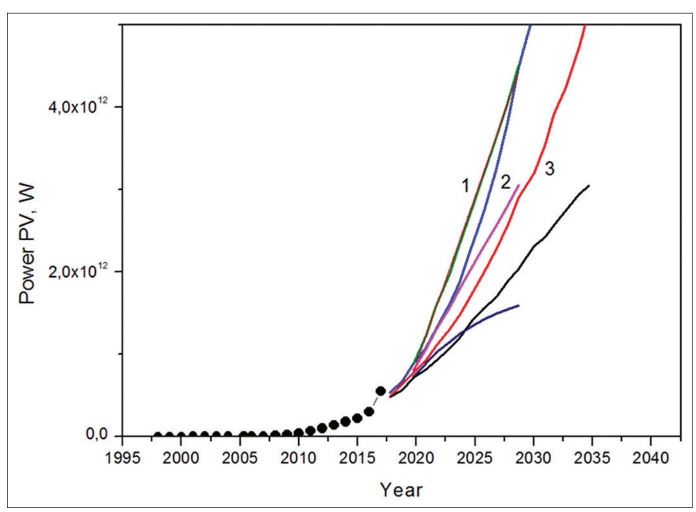
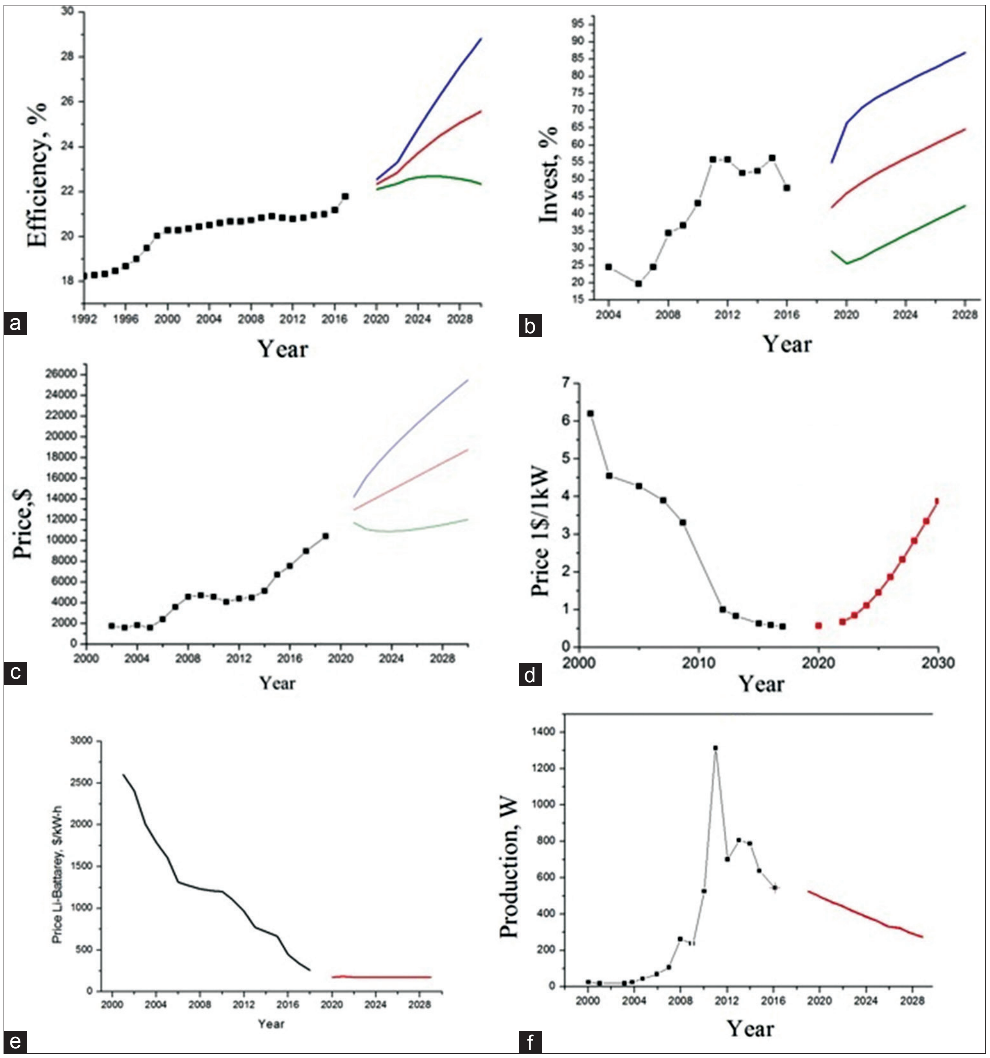


Table 1: Calculated correlation coefficients

Indicators	PPMCC	Spearman's rho	Kendall's tau
PV			
Price of PV module, $/W, Bloomberg GW, EPI	−0.86696	−0.97216	−0.9332
Price of Li-Ion Battery, Bloomberg $/W, EPI	−0.72428	−1	−1
Price of LI $, Metalery	0.92975	0.91534	0.80002
Efficiency in %, Fraunhofer, ISE	0.89277	0.97008	0.90924
Production Si PV MWp, Fraunhofer, ISE	0.69828	0.92705	0.78487
Investments in Solar Energy %, Our World in Date	0.68328	0.82457	0.677
GPV	0.70126	0.9842	0.93123
GPV+Invest	0.92249	0.87369	0.73855
GPVdiff+Invest	−0.36526	−0.21404	−0.12309

Figure 5: Expected progress/regress curves: (a) Silicon solar panel efficiency, (b) investment in photovoltaics, (c) Li prices (d) LIB prices, (e) >100-kW module prices, f) MW Silicon module production



One of the module production goals is to increase the module efficiency and to make it cost effective. The efficiency forecast for the period through to 2030 is in Figure 5a.

The forecast for economic factors is in Figure 5.

According to the optimistic forecast (Figure 5a) made for the efficiency of silicon solar modules, it will reach its abstract limit by 2030 (Yoshikawa et al., 2017). Now there is a difference between the abstract and real limits. Since 1980, there were only 16 successful laboratory cases of cell efficiency improvement, but only five thereof were by firms that produce commercial cells (Surek, 2003). Most of the cases were conducted by universities that do not have enough experience in large-scale production (Nemet, 2006). The scale of production affects the possibility of improving module efficiency in the lab, so investments in this field will lay ground for such a possibility. In addition, investments in PV industry are also of great importance. Based on data available from (Nemet, 2006), solar module efficiency has been improved during the period from 1983 to 1990, as the amount of money invested worldwide was USD 1.5 billion. Our forecast indicates that investments in PV will increase by 10% by 2030 (Figure 5b). Thus, efficiency increase can also be explained by the increase in investments in PV, although the pessimistic forecasts indicate that this figure will decrease first (Figure 5b).

As the case may be as we predict, new production technologies will enter the market, intended for silicon module production, as the silicon module production will decrease down to 250 MW by 2030 (Alamri and Alsadi, 2017; Crisp et al., 2017; Romeo et al., 2018). At the same time, the prices of silicon PV modules will rise (Figure 5e), so as the prices of lithium. This can be explained by the fact that its global reserves are exhausted. LIB prices are falling now (Blomgren, 2017), and according to the forecast (Figure 5), the price will settle about USD 100 per kW per h.

4. CONCLUSIONS

This research shows that PV development is tied (correlation coefficients are within 0.677–0.97) with a large number of difficult-to-introduce economic, social and technical factors. We have identified a number of reference factors: The efficiency of silicon solar modules, investments in PV, lithium prices, prices of rechargeable batteries, module prices, and silicon module production. The complex nature of relationship between these factors and our target dependence – installed PV capacity improvement – implies that the nature of these dependences will not change significantly over time, in fact – the changes will be interdependent and will spark one another. Based on this hypothesis, we have adjusted the forecast, significantly narrowing the confidence interval.

According to the forecast, power output will increase up to 210^{12} W by 2023 (optimistic forecast). Nevertheless, prices of silicon solar modules will increase over time, while the silicon panel production will go down. Unlike the Fraunhofer forecast, our forecast of PV development will not be as rapid, since we referred to all the factors.

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