Effect of solar energy policy on solar power efficiency in the European Union countries

Katarzyna Frodyma[1], Monika Papież[2], Sławomir Śmiech[3]

Abstract

The aim of this study is to assess the impact of solar energy policy on the efficiency of solar power in the EU countries. We apply two-stage Simar and Wilson, 2007 approach for cross-sectional data representing 24 EU countries. In the first stage, an input-oriented bias-corrected DEA model is applied to assess the efficiency of solar power potential regarding different aspects of solar power generation. In the baseline model, the global horizontal irradiance (GHI), which represents solar potential, is considered as the input variable. Solar-generated electricity is the output variable. Other specifications take into account environmental and economic aspects in addition to solar-generated electricity. In the second stage, the bias-corrected solar power efficiency scores are used in a truncated regression (Simar and Wilson, 2007) to explain the impact of solar energy policy on the relative solar power efficiency scores in the EU countries in 2016. Two main conclusions can be drawn. Firstly, additional benefits of solar power are limited to the group of countries with a relatively high share of solar power. Secondly, economic incentives positively affect the efficiency of solar power potential.

Keywords: *bias-corrected Data Envelopment Analysis (DEA) model, solar power generation*

JEL Classification: *C59, C61, Q2, Q01*

1. Introduction

Over the last two decades the EU member states have been implementing common energy policy regarding the development of renewable energy sources. The national renewable targets for each EU member state are specified by the European climate and energy package. Each EU country has created its own national renewable energy action plan to meet this target.

Two aspects of solar power development should be considered. Firstly, the EU countries are very diverse in terms of their solar potential, which has a significant impact on the supply of a given energy source. As a result, the high viability of investment is expected. Secondly, each country provides its own energy policy and supports the development of e.g. solar power by offering specific incentives, such as feed-in tariffs, green certificates, promotional loans, investment grants, and tax exemptions. However, a broader perspective reveals that the development of renewable energy sources leads to positive changes in the natural environment and decreases the costs of importing energy sources. The assessment of the viability of investment in solar power should take all these factors into account.

[1] Corresponding author: Cracow University of Economics, Department of Statistics, 27 Rakowicka St., 31-510 Cracow, Poland, frodymak@uek.krakow.pl.

[2] Cracow University of Economics, Department of Statistics, 27 Rakowicka St., 31-510 Cracow, Poland, papiezm@uek.krakow.pl.

[3] Cracow University of Economics, Department of Statistics, 27 Rakowicka St., 31-510 Cracow, Poland, smiechs@uek.krakow.pl.

A number of studies try to explain the dynamics of the development of renewable energy. They usually examine the role of different aspects of energy and climate policy. Best and Burke (2018) investigate the role of carbon pricing in the adoption of solar or wind power and Nicolini and Tavoni (2017), Li et al. (2017), Dijkgraaf et al. (2018), Best and Burke (2018) and García-Álvarez, et al. (2018) analyse the effect of the feed-in tariff (FIT) efficacy on the development of solar power. Romano et al. (2017) examine the influence of informal institutions on renewable strategy development, fiscal incentives, and public investments. All these studies focus on the capacity (generation) of renewable energy achieved by countries or the share of renewable electricity generation in total electricity generation. However, only several of them admit that energy policy can result in inefficiency, redundancy or overlapping of renewable energy (see Del Río and Mir-Artigues, 2014). The efficiency of renewable energy is a frequently studied issue. Most papers use Data Envelopment Analysis (DEA) as the empirical framework. There are only few studies which analyse solar power efficiency (Sueyoshi and Wang, 2017 and Frodyma et al., 2018). However, to the best of our knowledge, the effect solar energy policy experts on efficiency has not been studied so far.

The aim of this study is to assess the impact of solar energy policy on the efficiency of solar power in the EU countries. We apply two-stage Simar and Wilson, 2007 approach to cross-sectional data representing 24 EU countries.

In the first stage, an input-oriented bias-corrected DEA model is applied to assess the efficiency of solar potential regarding different aspects of solar power generation. In the baseline model, the global horizontal irradiance (GHI), which represents solar potential, is considered as the input variable. Solar-generated electricity is the output variable. Other specifications take into account environmental and economic benefits in addition to solar-generated electricity.

In the second stage, the bias-corrected solar power efficiency scores are used in a truncated regression (Simar and Wilson, 2007) to explain the effect of solar energy policy on the relative solar power efficiency scores in the EU countries. Three bundles of policies regarding economic instruments, policy support and regulatory instruments related to solar energy policy target are considered.

Our contribution to the literature is manifold. Firstly, the approach adopted in the study is based on a comprehensive view of the solar power efficiency on the country level. The study assesses not only the technical efficiency, which transforms solar power investment into electricity generation, but additionally considers economic and environmental benefits, which seem to play a crucial role and have motivated the EU legislation in this area. Secondly, the study assesses the effect of three areas of solar energy policy on the efficiency of solar power in the analysed countries. The assessment of their influence could prove beneficial for policymakers, as it points at possible constraints to be taken into consideration while deciding on renewable energy policy.

2. The two stage Simar and Wilson procedure

Data envelopment analysis (DEA), proposed by Charnes at al. (1978), is a mathematical programming approach to the construction of frontiers and the measurement of the efficiency of

DMU concerning the constructed frontiers. Technical efficiency measures the ability of a DMU to achieve the possible maximum level of output Y conditional on an input level X. There are two approaches in basic DEA: input-oriented and output-oriented. The first one maximises the proportional reduction of inputs X to maintain the outputs constant Y. The second one maximises the proportional increase of outputs Y for constant inputs X. A large number of papers explain the DEA estimates of efficiency with an additional set of exogenous factors. Regression models are used in this context.

Statistical properties of the efficiency scores and regression applied were extensively studied by Simar and Wilson (2002). Since the DEA efficiency scores are serially correlated, the standard inference procedure is invalid. They proposed a two-stage procedure. In the first stage, a consistent bootstrap procedure to correct the bias and to provide a statistical inference of the technical efficiency measures is applied. In the second stage, a truncated bootstrapped (Tobit) regression is used, which, according to Simar and Wilson (2007), provides the only feasible inference tool in the second stage.

3. Data

The empirical part of this study incorporates two above mentioned stages based on different datasets.

The first one, used in the bias-corrected DEA method, contains an input variable and a subset of three output variables. The selection of input and output variables is based on literature (Sueyoshi and Wang, 2017). Global horizontal irradiance (GHI), which is the total amount of shortwave radiation received from above by a surface horizontal to the ground, is considered as the input variable (Best and Burke, 2018). This value is of particular interest to photovoltaic installations and includes both direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI). The data for Global Horizontal Irradiance are obtained from the Global Solar Atlas[4].

Solar-generated electricity (TWh per capita) in 2016 (GEN) and two variables which describe the environmental and economic benefits resulting from the replacement of conventional energy with solar power are considered as the output variables. The economic aspect of solar power[5] (ECON) measures the economic benefit of avoided costs of generating electricity from fossil fuels after replacing conventional energy with solar power (per capita), while the environmental aspect of solar power[6] (ENV) measures the environmental benefit of avoided carbon dioxide (CO2) emissions by replacing conventional energy with solar power (per capita). All data describe 24 European Union countries (excluding Latvia and Estonia, which do not gener-

[4] https://globalsolaratlas.info/ accessed on 15.03.2019.

[5] $ECON = \frac{CFF}{\sum_{i=1}^{3} GEN_i} \cdot GEN$, where: $CFF = \sum_{i=1}^{3} GEN_i \cdot price_i$; where i indicates: coal, oil, natural gas, GEN_i – total primary energy supply generated from i energy sources in 2016, GEN – gross electricity generation from solar per capita in 2016.

[6] $ENV = \frac{CO_2}{TGEN} \cdot GEN$, where: CO_2 – values in fossil CO_2 is expressed in Mt CO_2/year, TGEN is total gross electricity generation, and GEN is gross electricity generation from solar power per capita in 2016.

ate any solar power in the analysed period, and Finland and Sweden for which there is no global horizontal irradiance data) in 2016 and are obtained from the European Commission webpage[7].

The second dataset used in the truncated bootstrapped regression is directed at assessing solar energy policies affecting the efficiency of solar power in 24 EU countries. The efficiency scores of the analysed countries obtained from the bias-corrected DEA method are used as the dependent variable. Three bundles of policies regarding economic instruments (EI), policy support (PS) and regulatory instruments (RI) which are linked with the solar energy policy targets are considered as independent variables. Following Marques and Fuinhas (2012), Aguirre and Ibikunle, 2014; Polzin et al., 2015, and Liu et al., 2019, the three bundles of policy instruments are measured by the number of active policies in a country per year regarding the solar energy policy target (in previous studies they were called "accumulated number of renewable energy policies and measures (ANPM)"), and they are obtained from the IEA's Global Renewable Energy Policies and Measures[8].

Economic Instruments (EI) include the following types of policy instruments: direct investment, fiscal and financial incentives support (feed-in tariffs, grants and subsidies, loans, tax relief, taxes, user charges) and market-based instruments (GHG emissions allowances, green and white certificates). These types of policy instruments are designed to reduce the investors' risk and provide a tool for trading and meeting renewable energy obligation among producers. They promote direct investment aimed at reducing the capital cost of investments in renewable energy.

Policy Support (PS) includes two types of policy instruments which define strategies and outline specific programs aimed at promoting renewable capacity inside a country, i.e. institutional creation and strategic planning.

Regulatory Instruments (RI) include the following types of policy instruments: auditing, codes and standards, monitoring, obligation schemes and other mandatory requirements. These policy instruments impose requirements on the minimum amount of electricity supplied mainly from renewable sources.

4. Results

To analyse the efficiency of the EU countries regarding their solar power investments, the study considers four models with global horizontal irradiance as the input variable, and selected combinations of the output variables. The models are presented in Table 1. The X indicates the variables which are used in particular models.

[7] Energy datasheets: EU-28 countries (https://ec.europa.eu/energy/en/data-analysis/country) accessed on 12.03.2019.

[8] International Energy Agency: https://www.iea.org/policiesandmeasures/renewableenergy/ accessed on 15.02.2019.

Table 1. Input-output variables of four models

	M1 *GEN*	*M2* *GEN_ECON*	*M3* *GEN_ENV*	*M4* *ALL*
GHI	X	X	X	X
GEN	X	X	X	X
ECON		X		X
ENV			X	X

The results of the bias-corrected DEA analysis, i.e. the bias-corrected efficiency scores (θ) of the EU countries in 2016 in all five models, are reported in Fig. 1 a-c. Fig. 1a-c present the efficiency scores obtained by model M1-GEN and by M2-GEN_ECON, M3-GEN_ENV, and M4-ALL models. The countries are ranked in a descending order according to the value of the bias-corrected efficiency scores obtained from the first (baseline) model with electricity genera-tion (M1-GEN) as the only output variable. These figures allow for comparing the results of the first model (M1-GEN) with the remaining models which include additional aspects.

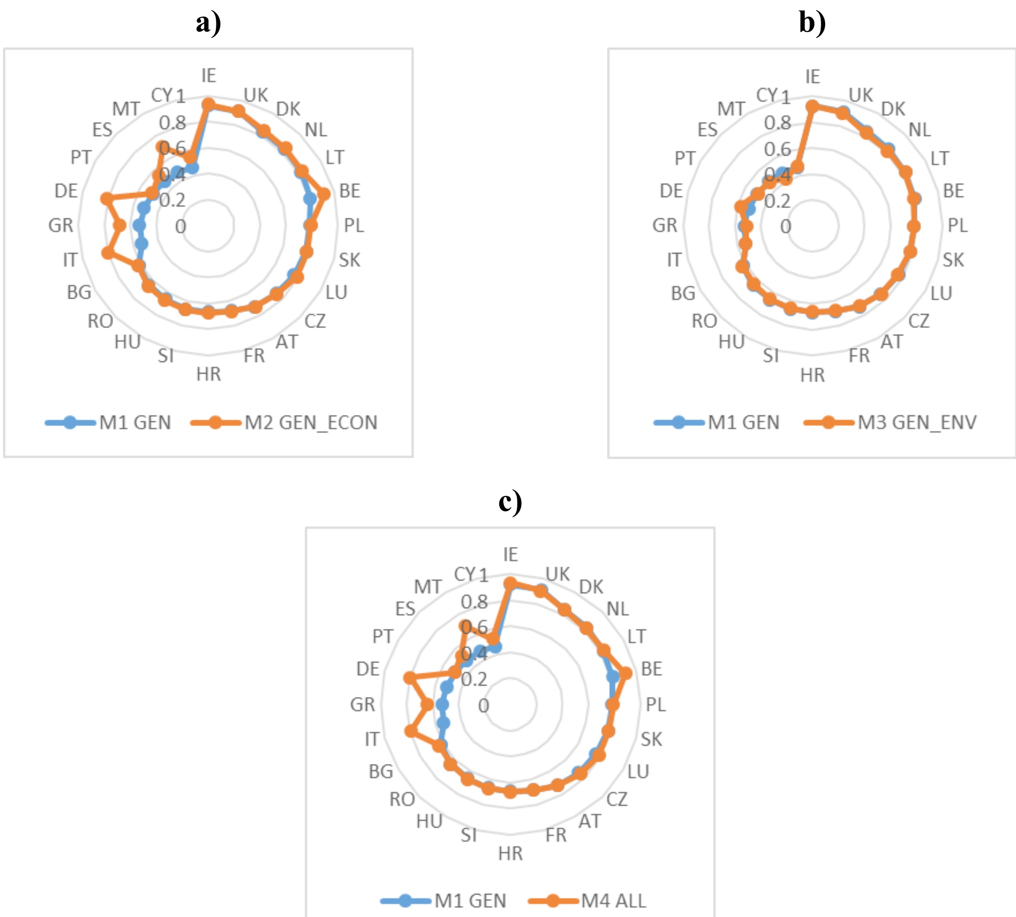

Fig. 1. The bias-corrected efficiency scores of the EU countries in 2016 obtained by M2-GEN_ECON, M3-GEN_ENV, M4-ALL models

Fig.1 demonstrates that in the baseline model, (model M1-GEN), Ireland and the United Kingdom are the most efficient countries in terms of their solar power potential. Their efficiency scores are the highest in all analysed countries and range between 0.902 and 0.915. Cyprus and Malta are the least effective countries.

Fig. 1a indicates that Ireland, Belgium, and the United Kingdom are the most efficient countries in terms of solar power potential when solar-generated electricity and the economic output (M2-GEN_ECON) are taken into account. Moreover, Germany, Italy, and Malta gain the most, and their relative efficiency scores increase by 56%, 50%, and 49%, respectively. An increase in the relative efficiency scores and a higher position in the rank are observed in countries using oil or gas as the main energy source (i.e. Ireland, in which in 2016 as much as 50% of total electricity generation comes from heating gas, in Italy – 44%, in Malta in which in 2016 as much as 84% of total electricity generation comes from heating oil power plants). Fig. 1b shows that Ireland, the United Kingdom, Denmark, Lithuania, Netherlands, and Belgium are the most efficient countries when solar-generated electricity and the environmental output are investigated (model M3-GEN_ENV). In addition, Germany and Cyprus gain the most in terms of environmental benefits. Fig. 1c points out that Denmark, Lithuania, and the Netherlands join the group of most efficient countries when all benefits are considered (model M5-ALL). In other words, Germany (where the efficiency score increases by 57%), Italy (493%) and Malta (48%) gain the most. In this model, Portugal turns out to be the least efficient country.

Table 2. The results of the truncated bootstrapped regression models

	M1	*M2*	*M3*	*M4*
	GEN	*GEN_ECON*	*GEN_ENV*	*ALL*
EI	0.0086	0.0205**	0.0102	0.0204**
SP	–0.0296	0.016	–0.0323	0.0148
RI	–0.0529**	–0.0455***	–0.0529***	–0.0478***
const	0.7201***	0.6962***	0.7117***	0.6944***

Note: Calculations obtained using STATA program; ***, **, * indicate statistical significance at 1, 5 and 10 per cent level of significance, respectively. Bootstrapped regression models are performed using the Stata “simarwilson” command.

The next stage of the study investigates the impact of renewable energy policy on the solar power efficiency in the analysed countries. Table 2 reports the results of the truncated bootstrapped regression models.

The results (Table 2) reveal that the effect of solar energy policy on solar power efficiency in the EU countries is significant, yet ambiguous. In two models (M2-GEN_ECON and M4-GEN_ALL) the bundles of policies regarding economic instruments (EI) (i.e., direct investment, fiscal and financial incentives supports, feed-in tariffs and market-based instruments, etc.) have a significant and positive effect on the solar power efficiency in the EU countries. It implies that the impact of fiscal and financial incentives, feed-in tariffs, grants and subsidies on solar power efficiency is notably strong. These types of policy instruments have large positive effects on solar energy promotion and play a substantial role in the assessment of the efficiency of solar potential when economic and environmental benefits are considered in addition to solar-generated electricity.

In contrast with economic instruments, the results obtained in the study demonstrate that the relative efficiency of solar potential in particular countries is negatively correlated with the number of active policies regarding regulatory instruments. So, the bundles of regulatory instrument policies (RI), which include auditing, codes and standards, monitoring, obligation schemes and other mandatory requirements, exert a negative and significant effect on the solar power efficiency in the EU countries in all models. It means that packages of policy instruments that impose requirements on a minimum amount of electricity, mainly from renewable sources, do not stimulate the EU countries to use their own solar potential.

However, the bundles of policy support (PS), which covers institutional creation and strategic planning, have a positive but insignificant impact on the efficiency of solar potential when economic and environmental benefits are considered in addition to solar-generated electricity. When the other two models are considered, this impact of policy support on solar power efficiency is negative, but also insignificant.

To sum up, a positive impact on the solar power efficiency of each country is exerted mostly by economic instruments (EI), mainly fiscal and financial incentives, such as feed-in tariffs (FIT). These feed-in tariffs spur deployment and technological diversity and lower risks associated with renewable energy technologies faced by private sectors.

Conclusions

Two general conclusions can be drawn from the first step of the study. Firstly, the countries which have favourable conditions for solar energy development are rather inefficient. It means, however, that they do not utilize their natural potential, thus they should provide much more capacity in solar energy. Secondly, the environmental and economic benefits of solar power are significant in countries with relatively large shares of solar power in total electricity production (Italy and Malta) or in countries witch use coal (environment aspect) or oil (economic aspect) as important energy sources. In the remaining group of countries additional outcomes are rather meaningless.

In the second step, the three bundles of policies regarding economic instruments, policy support and regulatory instruments (RI) linked with solar energy policy target are used to explain the impact of solar energy policy on the efficiency of solar power in the European Union countries. The role of these political factors is significant, albeit rather ambiguous.

Solar power efficiency is positively related to the package of policies regarding economic instruments. This result is in line with other studies, e.g. the ones conducted by Nicolini and Tavoni

(2017), Li et al. (2017), Dijkgraaf et al. (2018), Best and Burke (2018) and García-Álvarez, et al. (2018) who confirm a positive effect of the presence of feed-in tariff policies on the development of solar energy in the European countries. The bundle of regulatory instrument policies has a negative effect on the development of solar energy. Similarly, Li et al. (2017) find that the regulatory instruments have a negative yet insignificant impact on the renewable energy development. Policy support including institutional creation and strategic planning has a positive but insignificant impact on the solar power efficiency when – in addition to solar-generated electricity – economic and environmental benefits are taken into account. When solar-generated electricity is considered as the output variable, the impact of policy support on the efficiency of solar potential is negative but insignificant. This result is rather unexpected, as it might be logically assumed that a clear long-term energy strategy is conducive to investment, as investors appreciate a long-term framework with a clear vision. On the other hand, Polzin et al. (2015) report a negative impact of policy support and regulatory instruments on renewable energy sources development.

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