Prospects for Solar Energy Development in Belarus and Tatarstan

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Abstract: This paper discusses the resource, technical, and economic potential of using solar photovoltaic (PV) systems in Belarus and Tatarstan. The considered countries are characterized by poor actinometric conditions and relatively low tariffs for traditional energy resources. At the same time, Belarus is experienced with solar power due to different incentive mechanisms that have been used over the past decade. Moreover, the cost of building solar power plants in Belarus in 2013–2017 was lower than the world average. The cost of electricity production is analyzed depending on the geographical location of sites and the type of owners of solar power plants (i.e., households, businesses and industrial enterprises, electricity producers). Using the data on the cost of photovoltaic systems as presented by IRENA and considering actinometric data for Belarus and Tatarstan, a long-term forecast of PV electricity cost is made. The moments of the break-even points and payback periods are defined for Belarus and Tatarstan.

Keywords: solar power; photovoltaic systems; cost of electricity production; electricity tariffs; capacity factor

1. Introduction

Rapid global warming and planet's ecological deterioration require from the world community an urgent increase in the share of carbon neutral types of energy [1]. Solar radiation is a source of energy available anywhere in required quantities, and is thus considereded to be the main energy source of future [2]. The economic development level of individual countries and their size, geographical location and energy sector features influence the strategies which can be used for energy transition [1].

The use of incentive mechanisms with respect to renewable energy sources has led to a significant growth in the photovoltaic world market, a decrease in the cost of PV systems, and an increase in the efficiency and reliability of this equipment [3–6]. The payback period for solar power plants and heat systems depends on their geographical location, purchase or consumer tariffs on electrical energy and heat, seasonality and daily consumption schedule, and state preferences [7–12]. For this reason, in some countries the break-even point has already been passed, while in others such technologies remain economically inefficient [13,14].

Global trends in solar energy are such that over the past ten years, there has been a decrease in the average construction unit cost of solar power plants of 15.3% per year, amounting to a decrease in the average cost of electricity production of 17% per year. In 2020, the world average cost of solar power plant construction was 883 USD/kWp,

and the cost of generation was 0.057 USD/kWh for new plants [15]. In EU countries, the average cost of generation varies from 0.04 to 0.08 USD/kWh [2].

Belarus and Tatarstan have similar climatic and actinometric conditions, as they are located at the same latitude and have a temperate continental climate (Figure 1, Table 1). The annual mean solar irradiation is 1072 kWh/m² for Belarus and 1095 kWh/m² for Tatarstan [16]. There is an irregular distribution of irradiation throughout the year. Sunshine duration exceeds 250 h per month only from May to August. In December and January, PV generation is practically absent [17].
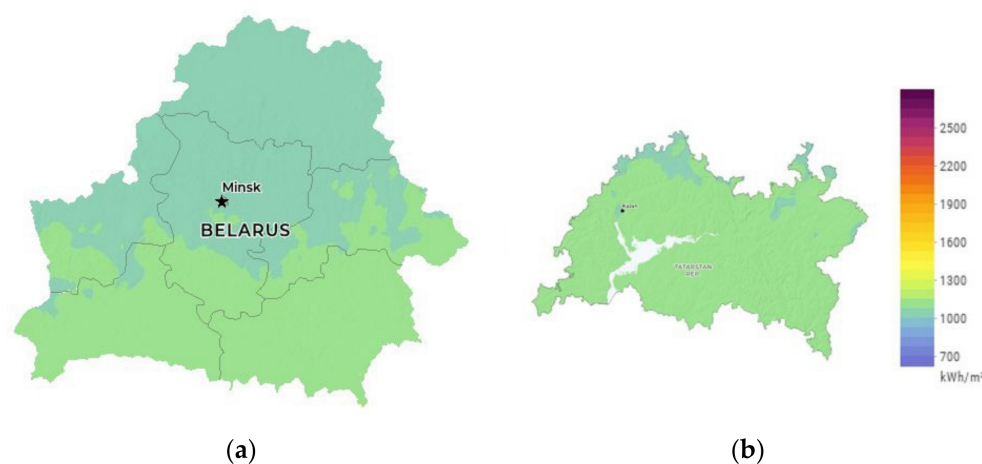

(a)　　　　　　　　　　　　　　　　　　　　　**(b)**

Figure 1. Average global horizontal irradiation in Belarus (**a**) and Tatarstan (**b**) [16].

Table 1. Comparative characteristics of Belarus and Tatarstan.

Characteristics	Belarus	Tatarstan
Area, thousand km²	207.6	67.8
Population, millions	9.3	3.9
Latitude	51°11′–56°10′	53°58′–56°41′
Average air temperature, °C	7.3	4.4
	6.2–8.4	3.7–5.3
Annual mean irradiation, kWh/m²	1073	1095
	1007–1142	1066–1124
Annual sunshine duration, h	1730–1950	1763–2066

Actinometric conditions determine the effectiveness of certain solar energy technologies. The brief duration of sunshine and high share of scattered solar radiation in Belarus and Tatarstan make solar thermal power generation technologies extremely ineffective. Concentrators used in such technologies operate exclusively on direct solar radiation [18]. Among photovoltaic technologies, polycrystalline silicon elements have the greatest efficiency in such cloudy conditions [19].

The low level of irradiation limits the average capacity factor (CF) of solar power plants. For Belarus, it cannot exceed 13.0% in the south-east of the republic, while for Tatarstan it cannot exceed 13.4% [16]. Placement of power plants in areas with less irradiation, deviation from the optimal orientation of solar modules, conversion and transmission losses further reduce the CF value. For comparison, the average CF of largest solar power plants in California is 29% [20].

In the Russian Federation, the minimum admissible CF of solar power plants is determined by regulatory enactments (14%). Construction of solar power plants in regions with a smaller CF is impractical and limited by tariff policy and rules for allocation of subsidies. Thus, construction of solar power plants in Tatarstan cannot be carried out within the framework of green energy support programs in the near future; however, other approaches to fulfill sustainable energy issues can be carried out [20,21].

The Belarusian energy balance is characterized by an extremely high level of energy imports. Low national reserves of traditional energy resources have led to a significant dependence on imports, primarily from Russia. 83.8% of the total primary energy supply is imported. In 2020, the net balance of energy imports was 21.7 Mtoe. Electricity consumption was 37 billion kWh in 2020 [22]. At the same time, Belarus has relatively low tariffs due to energy subsidies from Russia (Table 2).

Table 2. Average annual electricity prices in 2020, USD/kWh.

Customer Category	Belarus	Tatarstan
Household	0.076	0.056
Business	0.097	0.094
Prime cost	0.042	0.035

Tatarstan is a net exporter of energy resources due to its extensive oil reserves. It produced 32.7 Mt of oil in 2020, which is 6% of all oil produced in Russia. The annual consumption of primary energy resources was about 14.6 Mtoe in 2020. Electricity consumption was 29 billion kWh.

The tariff policy of Russia in relation to domestic consumers is such that the growth rate of electricity prices in national currency should not exceed the inflation rate. The level of tariffs in Belarus is linked to the cost of primary energy resources, the price of which is determined in USD and should not change in the medium term. Over the past decade, the average growth rate of tariffs in national currency in Belarus also have not exceeded the average inflation rate. This makes it possible to use in calculations the assumption that tariffs (in USD) will not grow in the near future and will remain at the level of 2020 (Table 2).

Currently, there are 41 countries that have achieved a total solar power capacity of over 1 GWp [23]. We have compared the economic and actinometric conditions in such countries with conditions in Belarus and Tatarstan (Figure 2). The vertical axis shows the range of average tariffs for households and industries for each country [24], while the horizontal coordinate corresponds to the maximum possible CF of solar power plants according to [16].
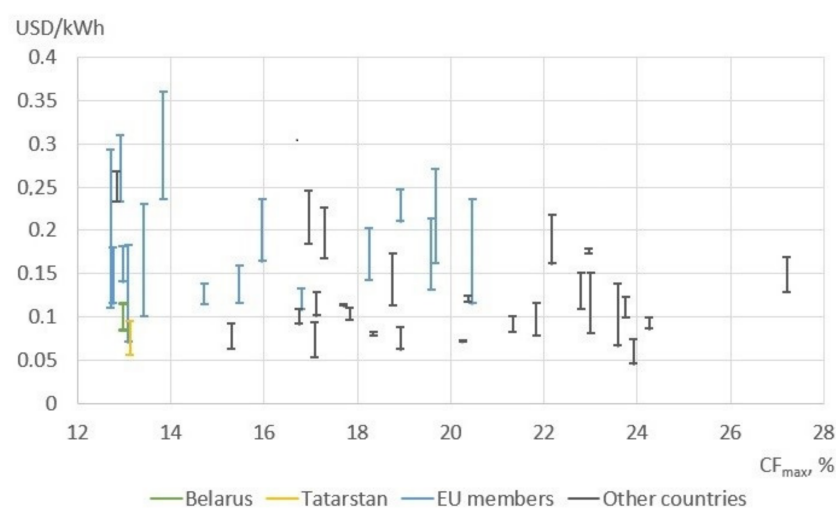

Figure 2. Comparison of Belarus and Tatarstan with leading countries by electricity price and maximum capacity factor of PV.

Most of the countries of Central and Western Europe have actinometric conditions similar to those in Belarus and Tatarstan (Germany, the United Kingdom, the Netherlands, Poland, etc.). At the same time, such countries have significantly higher electricity tariffs

for both households and industrial enterprises. However, even with high tariffs, additional measures of financial support are required [25,26]. Belarus and Tatarstan differ significantly from most of the EU countries in their tariff policy. Due to the presence of cross-subsidization of tariffs, the population pays for electricity at a lower price than business. In the EU the situation is the opposite, which is the reason 60% of solar power capacity is represented by residential and rooftop installations [2]. In addition, the populations in Belarus and Tatarstan have significantly lower levels of income, which does not allow for long-term investment.

Some developing countries are characterized by low electricity tariffs (China, India, Russia, etc.), while some regions of these countries have significantly higher solar irradiation and CF [16].

Leading countries that have achieved a high share of solar energy, at least in the early stages, used various incentive mechanisms such as green tariffs (most leading countries), tax incentives (USA, some EU countries), subsidies and soft loans, and renewable energy quotas for generation and construction companies (EU countries). Such support measures implemented by developed countries have caused intensive growth of the solar energy sector and a significant decrease in the unit cost of solar power plants [2]. For example, in Poland the state program "Mój Prąd" has since 2019 provided subsidies and tax benefits for investments in independent energy sources for households; 'prosumers' can get back 80% of the surplus energy supplied to the grid. This has led to a significant increase in the number of PV micro-installations, the capacity of which is now 77% of the total installed PV capacity in Poland [26]. Similar measures can be used by Belarus and Tatarstan.

Further development of the sector requires infrastructural and policy changes and implementation of innovative technologies. For example, introduction of auctions for solar power in EU countries decreased price levels for PV generated electricity and reduced the need for subsidies [2].

Due to government incentives, Belarus already has experience in operating solar power plants. Construction of commercial solar power plants began in 2011, after the adoption of the Law on Renewable Energy Sources and the introduction of incentive tariffs for the purchase of electricity. Initially, the ratio of the purchase rate for solar power plants to the commercial rate (incentive coefficient) was 3.0. Thus, the purchase tariff was 4.7 times higher than the prime cost of electricity in the Belarusian power system. Furthermore, customs duties on equipment using renewable energy sources were canceled [27].

The first solar power plants in Belarus were built mainly by individual entrepreneurs and non-commercial organizations, and had a capacity of 10–100 kWp. The boom in the construction of small solar power plants did not stop even with the decrease in stimulating purchase coefficient in 2014–2015. The number of signed investment agreements for large solar power plants have also increased (Figure 3) [28]. Since 2015, the maximum incentive coefficient has varied for power plants of different sizes [27].
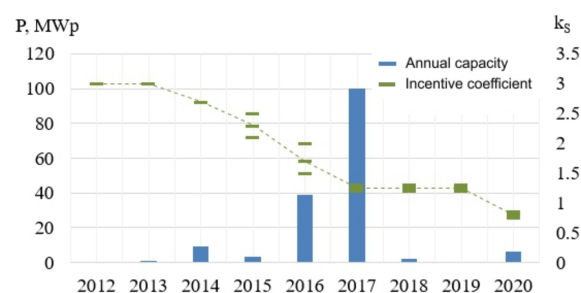

Figure 3. Dynamics of annual commissioning volume of solar power plants in Belarus, and maximum incentive coefficient.

In 2015, the Government of Belarus imposed restrictions in the field of renewable energy sources in the form of annual construction volume quotas. Quotas were introduced only for power plants that planned to use incentive coefficients. Holding ten-

ders for the allocation of quotas makes it possible to select stations that have the lowest incentive coefficient.

In recent years, mainly MW scale projects have been implemented. The average installed capacity of solar power plants in Belarus exceeds 1.9 MW. As of 1 January 2021, there were 100 operating power plants with a total installed capacity of 160 MW included in the Renewable Energy Sources Cadastre of Belarus. It was planned to build 11 power plants with a total installed capacity of 126 MW [28]. However, the implementation of these projects was paused.

In the coming three years, the issuance of permits for the construction of solar power plants with incentive coefficient will not be provided. Legal entities can still build solar power plants for their own needs without significant electricity sales to the grid [27].

Tatarstan has no experience in building solar power plants. At the same time, the Russian Federation has already built 1.8 GWp of solar power plants. The average cost of construction in Russia (1889 USD/kWp in 2020) is significantly higher than the world average [15]. According to IRENA, this value is the highest in the world. The cost structure is shown in Figure 4.
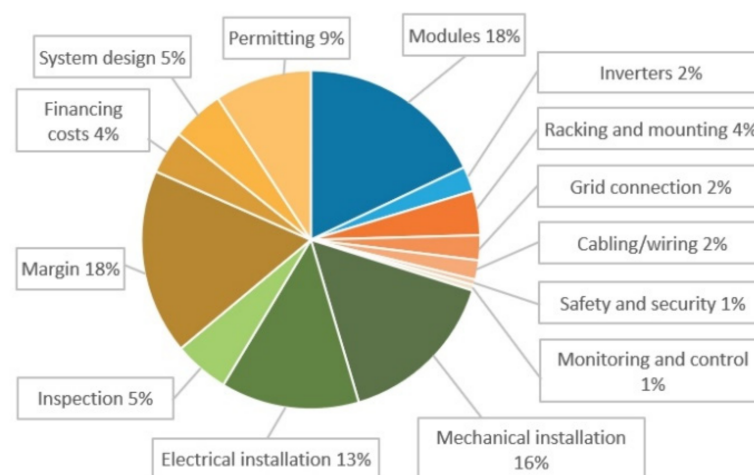

Figure 4. Cost structure of solar power plants in Russia in 2020. Data from [15].

Comparing this data with cost structures in other countries, it can be concluded that the cost of solar power plant construction in Russia can be reduced by decreasing expenditure on design, installation, commissioning and obtaining permits. The share of margin is the highest in price formation and can be obviously reduced. Reduction of these costs, in our opinion, will bring construction costs down to the world average.

The objective of the present comparative study is to assess the potential for using solar energy in Belarus and Tatarstan and to predict the moments when PV technology will become cost-effective in these regions. Such data are necessary for planning the development of power systems.

Methodologies for calculating resource and technical potentials for using solar energy for selected regions are well-established [29–31]. With the increase in PV statistics data, new approaches are emerging for assessing the potential and effectiveness of such systems based on big data and GIS technologies [32].

The area available for the placement of solar power plants should be determined considering social and environmental constraints. The following categories of land can be used for the placement of solar power plants:

- Unused—in full volume;
- Violated—in full volume;
- Settlements—part of the roof and facades;
- Agricultural—full volume or common usage with agricultural processes when it is profitable [33,34].

Forests, lands under trees and shrubs, swamps, and the territory of water bodies cannot be used for the construction of solar power plants due to environmental restrictions. Common land and land allocated for roads and transport cannot be used for the construction of solar power plants due to social restrictions.

Integration of PV systems in buildings is one of the best solutions because they do not occupy productive land, and their integration into the electricity system is relatively easy due to their proximity to the point of consumption [2]. Determining the potential for placing solar power plants in settlements requires data about the area, including on suitable roofs and facades of buildings. Accurate assessment of the technical potential of PV on buildings can be performed using detailed cadastre information about settlements. For most settlements and countries, all the necessary information is not available. Approximate calculations can be made using statistical data or GIS technologies [35–39]. Detailed assessment of the technical potential of building-integrated PV systems can be made by using data on building statistics and cadasters [40].

2. Materials and Methods

2.1. Methodology of PV Potential Assessment

The theoretical resource potential for the use of solar energy is determined by the average energy of solar radiation arriving at the surface of the region during the year [29]. This indicator is deliberately excessive. There are different databases and GIS-based software that are used to calculate the theoretical potential [41]. We used the estimations made in the Global Solar Atlas [16].

Technical potential is equal to the average annual electricity generation, considering the minimum modern level of technological losses (LTL) when filling the allocated area with photovoltaic modules:

$$W = W_0 \times K_{SE} \times (1 - LTL), \tag{1}$$

where W_0 is the theoretical potential, toe/year and K_{SE} is the share of area that can be used without social and environmental restrictions.

The modern level of technological losses can be calculated by formula [29]:

$$LTL = 1 - \eta_{mod} \times \eta_{inv} \times (1 - \xi_{sys}), \tag{2}$$

where η_{mod} is the highest PV modules efficiency, η_{inv} is the highest invertor efficiency, and ξ_{sys} is the system losses. Nowadays, the most efficient serial photovoltaic modules have an efficiency of 23.0%. The most efficient solar inverters have an efficiency of 99%. System losses can be reduced down to 4% or less; thus, the modern level of technological losses in PV systems is 78.1%.

Within the project "Study of the effect of placing solar modules on buildings to improve energy security and energy efficiency, the development of clean energy in the Eastern Partnership countries" in 2017, an assessment was made of the technically possible potential of rooftop solar power plants in 19 cities of the Eastern Partnership countries, including Minsk, Mogilev, and Vitebsk [42]. In analyzing the data in this report, we noticed that for all of the studied cities the ratio of available roof area to population and to the total area of settlements was approximately the same. For the studied cities, there is an average of 20.3 m^2 of building roofs per one inhabitant, an average of 660 m^2 of roofing per hectare, and 44.5 kWp of photovoltaic modules can be placed per 1 hectare of urban land. We assumed that such assessments of the available roof area could be applied for Belarus and Tatarstan, as building density is approximately the same as in other EaP countries.

The assessment of the economically feasible potential can be carried out by comparing the current tariffs for energy resources and the cost of electricity production at solar power plants for areas with similar actinometric conditions. Feasibility may differ for cases of supplying capacity to the wholesale market, replacing fuel and energy resources of enterprises and households.

2.2. Solar Electricity Production Cost Forecasting

We have compared the average cost of construction of solar power plants in Belarus with global trends (Figure 5). Global average investment costs (IC) were obtained from the report in [15], and we also used our own data on the twelve largest solar power plants in Belarus. The cost of construction in Belarus was slightly below the world average in previous years.
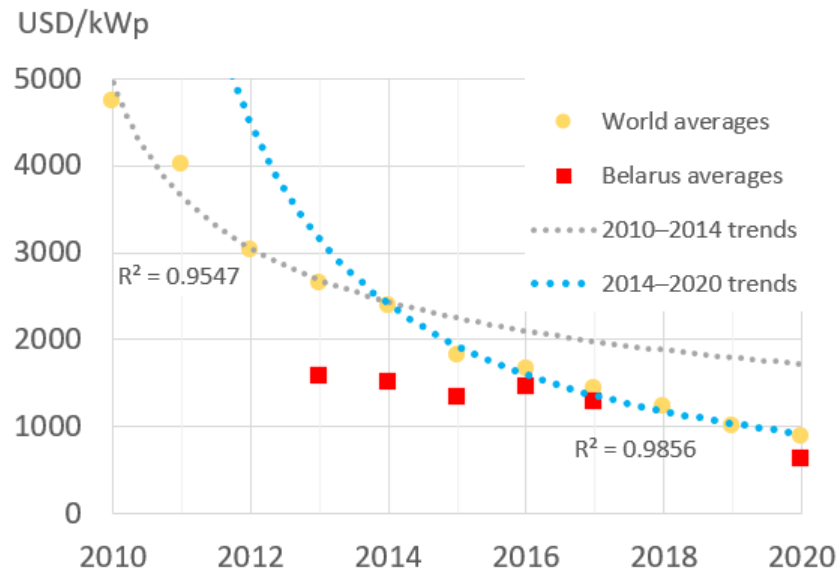
Figure 5. Dynamics of the average unit cost of solar power plant construction in the world and in Belarus.

Figure 6 shows the dynamics of average PV electricity generation cost in the world [15]. The presented factual data (dots on the chart) can be accurately approximated by power functions (determination coefficient is 0.98–0.99), with a sharp break in 2014. We used the 2014–2020 trend function as a forecast of PV generation cost in the future. This forecast is suitable for large solar power plants. Based on this forecast and data about actual cost of household PV systems from [15], we calculated the forecasting curves for small and medium-size PV systems as averages.
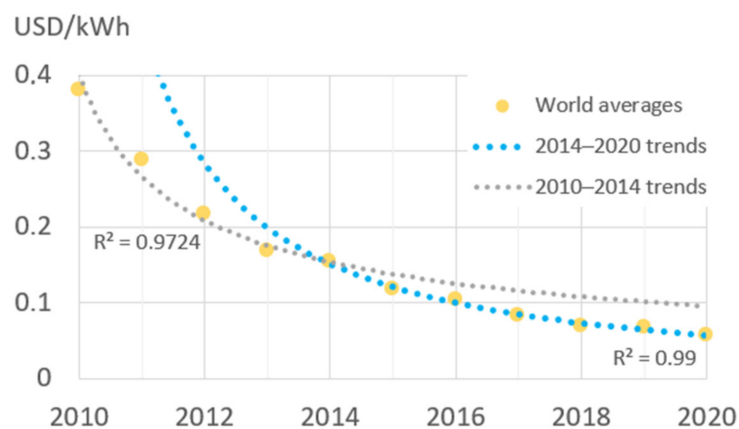
Figure 6. Dynamics of PV electricity generation cost in the world.

Assessments of the cost-efficiency of solar energy are usually made by using the levelized cost of energy (LCOE), which is determined as the ratio of the total investment,

operating and maintenance costs for a certain period to the amount of generated electricity [43,44]:

$$\text{LCOE(t)} = \frac{\text{IC(t)} + \text{LT} \times \text{OMC(t)}}{\sum_{i=0}^{LT-1} \text{CF} \times 8760 \times (1-\text{DR})^i}, \quad (3)$$

where IC(t)—forecasted unit investment cost, USD/kWp; LT—lifetime period, years; OMC(t)—forecasted annual unit operation and maintenance cost, USD/kWp·year; CF—capacity factor; DR—PV system degradation rate, year^{-1}.

We have assumed that unit operation and maintenance cost (OMC) does not depend on CF, but is determined by the size of PV system and remains the same during the lifetime period. Using the data of [15] on the LCOE and IC for different countries, we determined the world average OMC, which depends on the size of PV system.

The cost of construction of a solar power plant depends on the system size [43]. The specific cost of construction of small roof-based systems is 27.7% higher than for large commercial power plants. At the same time, the levelized cost of electricity (generation cost) is 15.7% higher for small systems [15]. We assumed that cost of large power plants with a capacity of over 10 MW would be close to the global weighted average cost.

The dependence of the LCOE on power source CF [45] enables us to calculate the PV electricity cost for a given region using world average LCOE:

$$\text{LCOE(t)} = \text{LCOE}_0 \text{(t)} \times \text{CF}_0/\text{CF}, \quad (4)$$

where LCOE(t) is the LCOE forecast function for the selected region, USD/kWh; LCOE_0(t) is the world average LCOE forecast function, USD/kWh; CF_0 is the world average capacity factor; and CF is the capacity factor for the selected region.

The definition of the moments when payback periods will take a certain value was based on the comparison of LCOE during the payback period with the electricity price for certain types of consumers:

$$\text{LCOE(t)} = \frac{\text{IC(t)} + \text{PP} \times \text{OMC(t)}}{\sum_{i=0}^{PP-1} \text{CF} \times 8760 \times (1-\text{DR})^i}, \quad (5)$$

where PP—payback period, years.

3. Results and Discussion

3.1. Resource and Technical PV Potential Assessment

Using geographic and actinometric data and the structure of land funds, we calculated the values of resource and technical potentials for the use of solar energy in Belarus and Tatarstan (Table 3). There are 419.1 thousand ha of unused and disturbed lands in Belarus. A part of this land is contaminated with radionuclides, which is not a barrier for solar power plant construction. In Tatarstan, there is much less unused and disturbed lands, roughly 40 thousand ha.

Table 3. Resource and technical potential for using solar energy in Belarus and Tatarstan.

Characteristics	Belarus	Tatarstan
Energy consumption, Mtoe/year	25.9	14.6
Resource potential, Gtoe/year	19.2	6.4
Technical potential, Mtoe/year, including:	1783.9	964.0
Unused and disturbed lands, Mtoe/year	84.8	8.3
Settlements, Mtoe/year	1.1–1.5	0.3–0.5
Agricultural lands, Mtoe/year	1697.6	955.2

In Belarusian settlements there are up to 259 million square meters of suitable roofs, which can store from 12.9 to 17.8 GWp of solar power plants. In Tatarstan there are up

to 79 million square meters of roofs, with PV potential from 3.6 to 5.4 GWp. The average capacity factor of such power plants is 11.2% in Belarus and 11.5% in Tatarstan.

The largest available areas correspond to agricultural lands, which can be used only with extremely high economic downsides.

3.2. Solar Electricity Production Cost Forecasting

Using Equation (3), we have made forecasts for levelized costs of electricity produced by large, medium and small PV systems in Belarus and Tatarstan (Figure 7), assuming that the cost of construction of solar power plants will be equal to the world averages. The horizontal lines on the charts indicate the tariff level for the selected type of consumer. The intersection of the forecast line with the tariff level corresponds to the moment when solar power plants become cost-effective for this type of consumer. Then, using Equation (5) we have defined moments when a newly-constructed PV system will have a payback period of 5 and 10 years (vertical lines on charts).
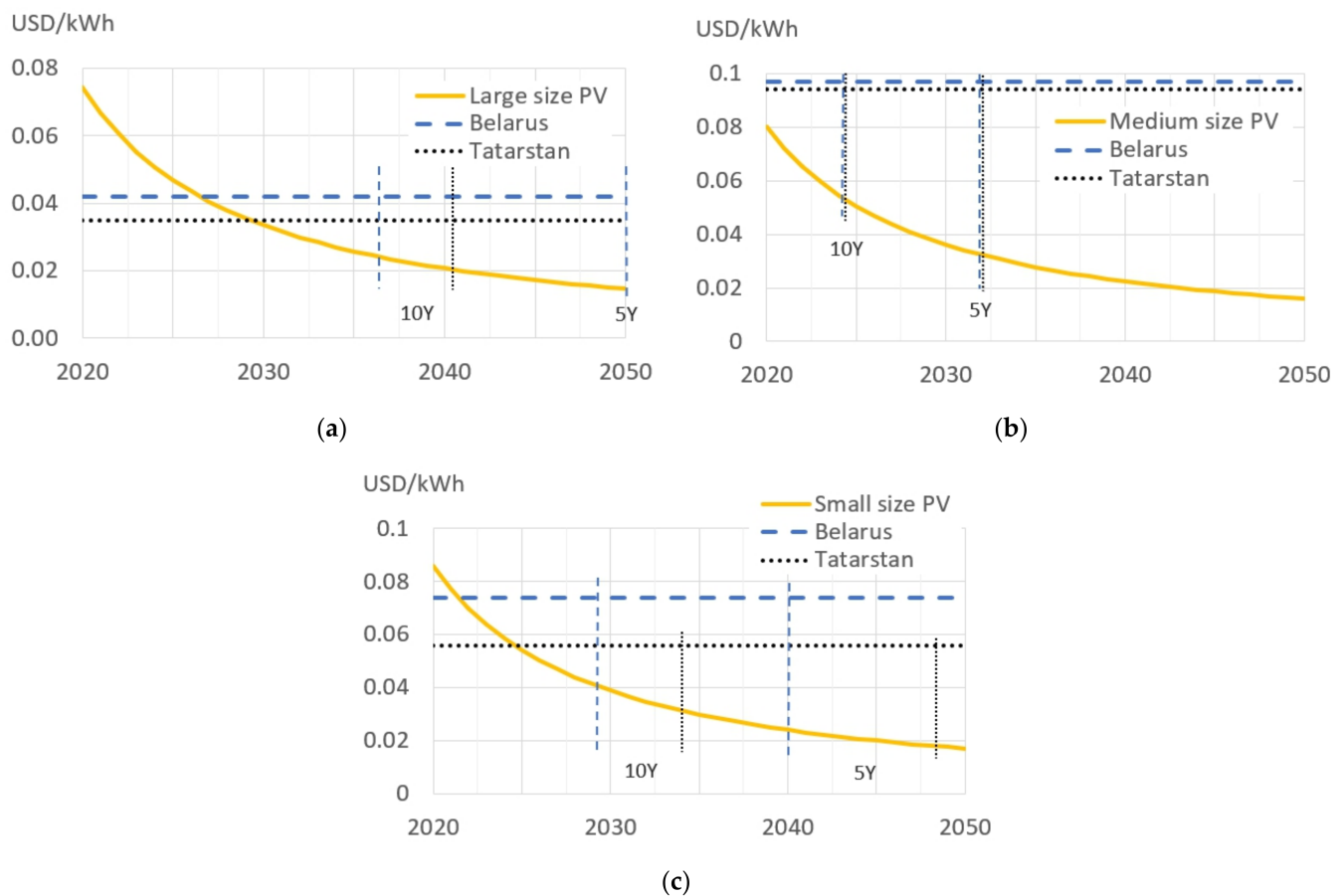
(**a**)

(**b**)

(**c**)

Figure 7. Forecast of levelized cost of electricity produced by (**a**) large, (**b**) medium-size, and (**c**) small PV systems compared to (**a**) average generation cost, (**b**) enterprise tariffs, and (**c**) household tariffs.

In 2020, the predicted average cost should be equal to 7.4 cents per kWh. The price slightly varies for certain regions of the republics due to different actinometric conditions. For Belarus, the range of costs is 0.071–0.079 USD/kWh. For Tatarstan, it is 0.069–0.075 USD/kWh.

As follows from the charts, only medium-sized solar power plants that are used to supply industrial enterprises are economically viable at the moment. However, even in this application, the payback period exceeds ten years. The payback period for industrial enterprises will be equal to ten years in 2024 and five years in 2032.

By 2030, the cost of generation in Belarus and Tatarstan may reach 3.4 cents, and by 2050 it may reach 1.5 cents. Large commercial power plants will become cost-effective in 2026 for Belarus and in 2030 for Tatarstan. Achievement of a five-year payback period will be possible only in 2050.

Small PV systems for households have the highest unit cost. At the same time, such consumers in Belarus and Russia have low tariffs due to cross-subsidization. For this reason, small PV systems will become cost-effective in 2022 for Belarus and in 2025 for Tatarstan. The payback period for households will be equal to ten years for systems built in 2029 for Belarus and in 2034 for Tatarstan. A five-year payback period will be achieved in 2040 for Belarus and in 2048 for Tatarstan.

It should be noted that the presented forecasts are made for the republics on average. For a number of consumers located in the southern regions or with higher tariffs, the payback periods are lower than the presented ones. This is confirmed by a number of industrial enterprises in Belarus operating their own solar power plants.

4. Conclusions

Realizing the importance of reducing greenhouse gas emissions and diversifying the types and suppliers of energy resources, Belarus and Tatarstan are taking measures to increase the share of renewable energy sources in their respective energy balances. Unfortunately, due to poor actinometric conditions, solar energy is currently less attractive than other renewable and traditional energy sources.

At the same time, in the considered countries there are some incentives for the development of solar energy, such as zero import duties on the equipment, increased green tariffs for solar electricity (although this has been significantly limited in recent years), and the possibility of using the network infrastructure for the transmission of energy between generators and consumers of one legal entity.

Large resource and technical potentials which significantly exceed the internal needs of energy resources indicate that solar energy can become economically feasible in these countries in the future.

The Belarusian experience in solar energy shows that it is possible to decrease the cost of solar power plant construction in Russia by reducing margins and expenses on design, installation, commissioning, obtaining permits.

Reduction of construction cost could lead to the cost-effectiveness of PV systems for households and commercial power plants by the middle of the 2030s. PV electricity generation cost will become lower than average power system generation cost in 2026–2030.

The main directions of energy sector transformation over the next few years in order to ensure the energy transition should be the liberalization of the sector, creation of electricity markets, avoidance of cross-subsidization, implementation of renewable energy auctions, elimination of legal, technical and bureaucratic barriers for households to connect PV systems to grid, and improvement of access to financial resources for projects in the field of renewable energy sources.

Considering the peculiarities of the tariff policy in Belarus and Tatarstan, incentives for the development of solar energy should be redirected to medium-size PV systems built by business and industrial enterprises for their own purposes. While such consumers have the highest tariffs, they also have the financial resources for the construction of PV systems. This will allow intensive development of the solar energy sector with minimal subsidies.

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