MSc Program
Renewable Energy Systems

The challenges of utility-scale PV plant development in Ukraine

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 05.11.2018

Affidavit

I, **YURII DEHTIAROV, MBA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "THE CHALLENGES OF UTILITY-SCALE PV PLANT DEVELOPMENT IN UKRAINE", 111 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

In the modern world power production and its sources play the fundamental role in economic development and state security. In the 20th century electricity demand was provided with fossil fuel power plants and the greatest breakthrough was done by nuclear power. Nowadays many countries including Ukraine face the challenge of nuclear power replacement before or after its operation expire date with new sources of renewable age.

The purpose of this paper is to show whether cost competitive utility scale solar PV power plants deployment in Ukraine could help in replacement nuclear power in till 2035.

Thus the core objectives of this paper is to assess the electricity demand in Ukraine till 2035 caused by nuclear power phase out as well as the cost-competitive potential of utility scale solar PV power plants to cover such demand, barriers and policy instruments for realisation of such potential. These objectives were reached by data collection method and comparison approach of nuclear and solar PV power costs as well as assessment of current and suggested incentive solar PV support instruments.

This research shows that current balance of Ukraine electricity mix and electricity generation in peak load period as well as current incentive solar PV policy will constrain PV deployment in Ukraine after 2020 and would not make considerable impact on nuclear power replacement. Nuclear power with its base load function and low flexibility are strongly colliding with solar PV power and will constrain REN development in Ukraine. Only investment oriented changes in solar PV policy could partly bring positive results to nuclear power replacement with solar power by 2035.

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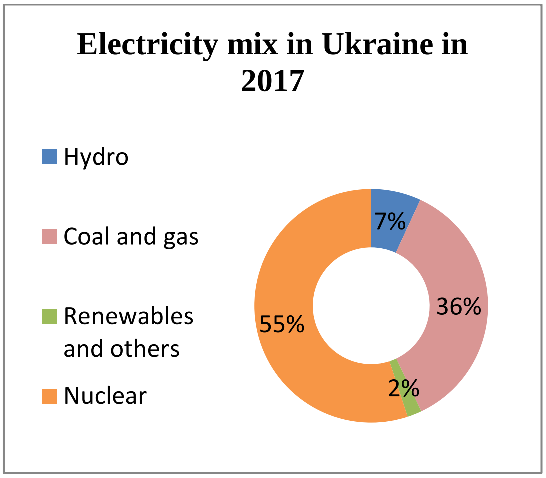
Chapter 1: Introduction

1.1 Motivation

In the recent years Ukraine has faced dramatic challenges in electricity sustainability caused by reduction in electricity generation. In particular under the information of State Statistic Service of Ukraine (SSS UA), that is presented at Figure 1.1, in 2017 electricity generation reduced by 25% from the base year 2013 after separation of electricity systems of the Autonomous Republic of Crimea, city of Sevastopol and the territory of defined areas of Donetsk and Luhansk regions.



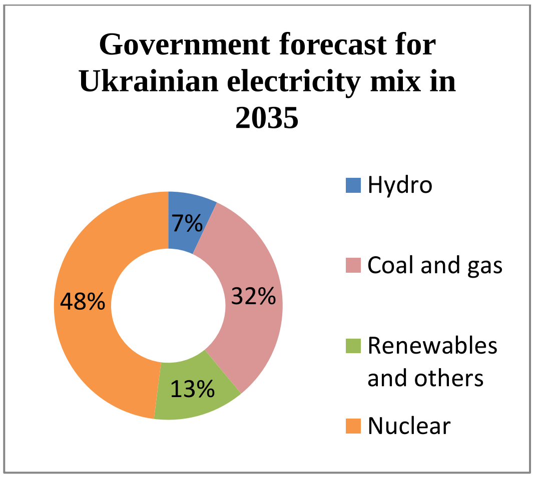


Fig. 1.1: Electricity mix in Ukraine in 2017
Source: State Statistic Service of Ukraine (2018a)
Fig. 1.2: Government forecast for Ukrainian electricity mix in 2035
Source: Strategy 2035 (2017)

But the future of electricity transformation in Ukraine still remains unclear. Under The Energy strategy of Ukraine till 2035, which was approved by the government of Ukraine on August 18, 2017 (Strategy 2035), power production should increase by 25% in 2035 and in particular generation from renewable energy sources (RES**)** including all hydro should increase to 20 % in Ukrainian electricity mix. Such Governmental scenario assumes reintegration of Autonomous Republic of Crimea, city of Sevastopol and the territory of defined areas of Donetsk and Luhansk regions before 2035. As could be seen from the Figure 1.2 the share of nuclear power and other fossil fuels like coal and gas will remain at a relatively high level.

In the Strategy 2035 it is also mentioned that from 2030 the process of nuclear power plants (NPP) phase out will start after 50 years of exploitation and till 2020 Government should decide which sources of electricity generation should be appropriate for replacement of the expired NPPs. But still Strategy 2035 declares that nuclear energy is worth utilization in Ukraine and its share in electricity mix should extend.

Starting from 2030 till the end of 2035, Ukraine should replace 4 835 MW of expired nuclear power capacities.

Thus Ukrainian Government instead of elaborating real energy transition strategy postpone this irreversible process for the future times still relying on nuclear power.

The Strategy 2035 simply witnesses that Ukraine still did not learn the lesson of Chernobyl catastrophe.

It is currently impossible to evaluate the actual costs and risks of generating electricity using NPPs. Most of these risks like nuclear disasters, fuel storage and threat of terrorism could emerge any time in the future as it was with Chernobyl NPP. The risks of so called “peaceful” nuclear power are so non-appraisable that insurance companies all over the world are not willing to cover risks that aroused from NPPs operations.

At the same time Germany, Belgium and Switzerland decided to phase out nuclear power while other countries have already completed the phase-out (Italy and Lithuania) or terminate its nuclear power programs.

Nowadays sustainable electricity supply could be reached by environmentally friendly, economically feasible, and what is more important by safe RES sources that are available in Ukraine.

Basically, solar PV in Ukraine could provide number of benefits comparing with nuclear power, being competitive with and independent from imported fossil fuels.

Thus the core aim of this paper is to show whether cost competitive utility scale solar PV power plants (SPP) deployment in Ukraine could help in replacing nuclear power in 2035. The positive answer and political will could bring a great challenge to the attraction of investments in the Ukrainian PV market development and influence Ukrainian Government to refuse from commencement at least of new NPPs in favour of real energy transition.

1.2 Research objectives and questions

The main objectives of this paper is to assess the electricity demand in Ukraine in 2035, the cost-competitive potential of utility scale SPPs and ways of realisation of such potential. These objectives will be achieved by answering the main question: "Could utility scale SPPs replace nuclear power capacities that are subject to phase out in Ukraine in 2035?"

In order to answer to the main research question this paper will focus on answering the following sub-questions:

1. How actual electricity demand in Ukraine could be changed in 2035?

To answer this question the general overview of Ukrainian electricity sector and in particular deep analysis of the nuclear power generation in Ukraine is given to show possible development of electricity demand in coming years as one third of Ukrainian NPP units would be phase out till 2035. Thus to assess the costs of future replacement of nuclear power capacities by the same fossil technology or with solar PV capacities the next questions should be answered.

2. What are the costs of new build nuclear power units?

Ukraine has no experience of building full cycle new nuclear power units under free competitive market rules and conditions. Thus the comprehensive analysis of new NPP projects in EU was provided as well as evaluation of costs of domestic competent bodies. To make comparison of NPP's costs and cost of solar PV power plants next two questions arise.

3. What solar PV capacity is available in Ukraine?

To answer this question the potential of solar PV utilization in Ukraine was given.

4. What are the costs for utility scale SPP in Ukraine?

To evaluate the investments costs of utility scale SPP and levelized costs of electricity (LCOE) of SPP in Ukraine, the economic lifetime of SPP, cost of financing, capital and operational costs and installed capacity utilization factor (ICUF) was taken into consideration.

5. And at last how much cost competitive utility scale SPP could be installed in Ukraine?

There are a lot of factors that influence the installation of utility scale SPPs. Among them are development of electricity demand in Ukraine, investments cost and LCOE of SPPs, power generation in peak load and base load in summer time, current and upcoming incentive solar PV policy, current trends and assumptions for future utility scale solar PV deployment policy in Ukraine.

1.3 Research boundaries

This research is restricted by assessment of the possibility and the amount of electricity that could be replaced by utility scale SPPs after decommissioning of the existing nuclear units till 2035. Coal and gas as source of electricity generation were not taken into account as these sources mostly operated by privet investors and only outdated figures could be reached in public sources.

It was also not taken into account the development of electricity sector in the Autonomous Republic of Crimea, city of Sevastopol and the territory of defined areas of Donetsk and Luhansk regions till 2035.

1.4 Data collection

Concerning the data collection, the method used is the collection and analysis of already existing data. The necessary material for this research is gathered from primary and secondary publications, as well as national and international databases and websites of national and international organizations and market players, interviews with local experts and officials.

1.5 Structure of the Master Thesis

The Master Thesis consists of 10 chapters.

Chapter 1: Introduction

Introduction includes motivation to the research topic that is primarily possibility of solar PV replacement of nuclear power in Ukraine, the objective to assess PV perspectives and main questions and research boundaries of the Thesis.

Chapter 2: Description of the Ukrainian electricity sector

This chapter make a view on Ukrainian electricity mix paying attention to nuclear and solar PV power generation.

Chapter 3: Outlook for electricity demand in Ukraine in 2035

Presents estimations of electricity demand development in Ukraine after 2030 when the process of nuclear power phase out will start.

Chapter 4: Nuclear power policies in EU

This Chapter includes description of nuclear power policies in EU and especially in Germany and Belgium where decision of phase out nuclear power were taken.

Chapter 5: Nuclear and solar PV power cost comparison

Outlook for nuclear and solar PV power costs for new build power plants are given in chapter 5 as well as their cost comparison as methodical approach of this paper.

Chapter 6: Barriers to utility scale solar PV deployment in Ukraine

This chapter includes technic, economic and market barriers for deployment of cost-competitive solar PV power plants answering the question of how much solar PV capacities could really replace nuclear power till 2035 and weather current PV policy constrain such deployment.

Chapter 7: Solar PV incentive policy. Current approaches, Ukrainian solar PV support policy

This chapter includes overview of existing solar PV incentive policy instruments, PV policy in Germany, Ukrainian legislation.

Chapter 8: Assessment of current solar PV incentive policy in Ukraine. Discussions on solar PV policy changes

This chapter includes the assessment of solar PV deployment till 2035 under current PV incentive policy in Ukraine. Include assessment of new PV possible policy instruments that could be applied starting from 2020.

Chapter 9: Assessment of two possible scenarios

In this chapter presented estimation of solar PV power production in 2035 under current PV incentive policy (Scenario “A”) and under new PV support instrument that envisage 20 years FIT duration (Scenario “B”).

Chapter 10: Conclusions and recommendations

The main conclusion is that only new instruments of PV incentive policy could bring positive impact on nuclear power replacement with solar PV power plants till 2035.

Chapter 2: Description of the Ukrainian electricity sector

Every country has its own specific electricity sector that is characterized by source of electricity generation, installed capacities, demand, consumption and others factors that influence this cornerstone sector of state economy. Ukraine is not exemption and this chapter presents key data to understand electricity mix in Ukraine and within the boundaries of this research, nuclear power generation and solar PV deployment are described in more details. These current basic data give the possibility to analyse in the next chapters the future electricity demand till 2035 development and ways to satisfy such demand in Ukraine.

2.1 Electricity generation in Ukraine

First of all it should be admitted that Ukraine is a post-Soviet state with old electricity capacities that mostly were built in 70^{th}-80^{th} years of the last century and at the same time with one of the cheapest retail prices in Europe. During all period of independence of Ukraine the electricity prices were rather a strong issue of political expediency. As a result the economic lifetime of most of the installed capacities rapidly goes to the end.

Four years ago Ukraine faced economic crisis which was followed with enormous inflation and made serious impact on Ukrainian electricity sector.

As could be seen from data of SSS UA reports used in table 2.1 electricity production in Ukraine decreased from 194 billion kWh in 2013 to 155 billion kWh in 2017. Such 25 % decrease was mainly influenced by withdrawal from state electricity system of coal generating capacities in Donbas region. Also starting from 2017 Ukraine is no longer supplying electricity to legislatively defined Donetsk and Luhansk regions.

At the same time the data of SSS UA as of June 22, 2018 shows the reduction of Ukrainian population to 42 million. But in reality near 4 million people still live in defined Donbas and Luhansk regions that are not part of Ukraine united electricity system and consume electricity that is locally generated and not considered in state electricity mix.

It could be also seen from the table 2.1 that reduction of electricity generation per capita was influenced mainly by dramatic GDP reduction relying on World Bank

Data. On the other hand visible decrease of electricity intensity of GDP was highly influenced by more than 300% local currency depreciation.

Table 2.1: Basic statistics

Indicator/Year	2013	2017[1]
Electricity generation	194 377 million kWh	155 414 million kWh
Population	45, 553 million	38,300 million
Electricity generation per capita	4 267 million kWh	4 057 kWh
Electricity consumption	163 918 million kWh	120 million kWh
Electricity consumption per capita	3 600 kWh	3 133 kWh
GDP per capita	US $ 4029	US $ 2639
Electricity intensity of GDP	US $ 1.1/kWh	US $ 0.8/kWh

Source: own table on the basis of State Statistic Service of Ukraine data (2018a, b and 2014) and World Bank data (2018)

In 2017 Ukraine's electricity consumption was approximately 22% below the electricity output level (144 883 million kWh) with 120 000 million kWh. The consumption of electricity by households and domestic industry made 42% and 58% respectively (SSS UA: 2018a).

Table 2.2 and chart 2.1 show that in 2017 55% of electricity production was provided by nuclear power, approximately 36% of electricity produced using gas and coal by Thermal Power Plants (TPP) and Combined Heat and Power Plant (CHPP), 7% - Hydro Power Plants (HPP) and Pumped Storage Hydropower plants (PSHPP) and others 3 % of which Wind Power Plant (WPP) – 1.1% and SPPs – 0.53%.

Actual data of SSS UA shows that in 2017 NPPs produced more electricity than other sources of generation capacities (see Table 2.2) with its electricity generation of 85 576 million kWh.

[1] Excluding the Autonomous Republic of Crimea, city of Sevastopol and the territory of defined areas of Donetsk and Luhansk regions

Table 2.2: Ukrainian power plants capacities and power generation in 2017

Source of electricity generation	Power plants capacity (MW)	Electricity generation (million kWh)	Electricity generation per capita (kWh)
Nuclear	13 835	85 576	2 234
Coal and gas	31 075	55 841	1 457
Hydro	6 213 (1500 PSHPP)	10 568	276
Wind	465	973	25
Solar	742	714	18
others	556	1 742	45
Total	**52 886**	**155 414**	**4057**

Source: State Statistic Service of Ukraine (2018a) and Minenergo (2018)

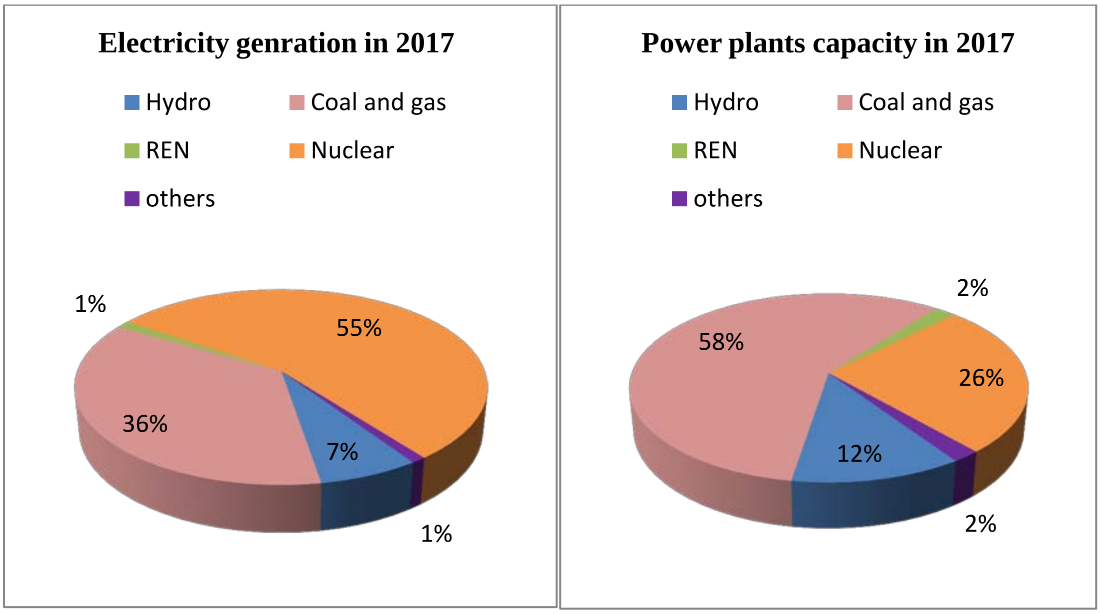


Chart 2.1: Shares of electricity generation and power plants capacities by sources in Ukraine in 2017
Source: own chart on the basis of the data of State Statistic Service of Ukraine (2018)

To summarise all abovementioned data it could be clearly seen that nuclear power nowadays plays significant role in electricity mix in Ukraine providing base load to electricity system. TPPs and CHPPs provide intermediate and partly peak load and HPP and PSHPP satisfy peak load at highest demand. On the other hand renewables and primarily solar PV only start its way for development. Also it is clearly seen that decrease in population and GDP fall will not come up with government expectation of extend of electricity demand in the future. At the figure 2.1 could be seen daily maximum peak load that was approximately 23 million kWh at 18 p.m., electricity generation/consumption schedules on February 1, 2018 that show maximum load by electricity sources in winter time. Figure 2.1 clearly shows that nuclear power in winter provides constantly more than 10 million kWh.

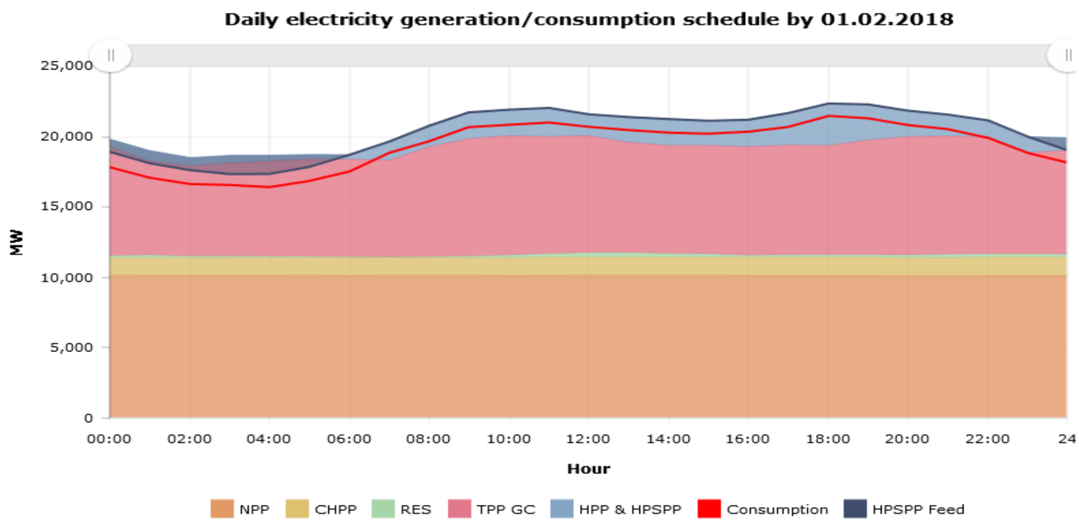


Fig. 2.1: Daily Ukrainian electricity generation/consumption schedule on February 1, 2018
Source: Ukrenergo (2018a)

Taking into consideration Ukrainian electricity mix, power capacities and power production as well as peak load, within the aims of this paper more detailed description of nuclear power and solar PV power capacities is presented below.

2.2 Nuclear power generation

As it was stated ahead in paragraph 2.1, nuclear power is a main source of electricity generation in Ukraine with its share of 55 % in electricity balance. To evaluate the reliability of nuclear power in Ukraine as source of electricity generation and needs for its replacement it is important to describe nuclear power sector more precisely.

There are four acting NPPs with 15 nuclear power blocks in Ukraine that generated 85 576 million kWh in 2017 (Table 2.3).

Table 2.3: Nuclear power capacities and generation by Ukrainian NPPs in 2017

	Name of NPP	**Installed capacity (MW)**	**Electricity generation (million kWh)**
1.	**Zaporizhia NPP**	6 000	34 500
2.	**South Ukraine NPP**	3 000	17 900
3.	**Rivne NPP**	2 835	19 793
4.	**Khmelnytskyi NPP**	2 000	13 383

Source: Minenergo (2018)

All NPPs are state owned and managed by state company "Energoatom". As showen at figure 2.2 two NPPs with installed capacity of 9 000 MW situated in the southern part of Ukraine in the sea shore Zaporizhzhya and Mykolaiv region and other two with 4835 MW capacity in Western part of the country. Also two power blocks are under construction.

The detailed description of Ukrainian NPPs with their dates of start of operation, terms of prolongation and likely close terms is presented in Appendix 1. It could be seen that all nuclear power blocks have Water-Water Energetic Reactor (VVER) type reactor with two range of capacity of 1000 and 440 MW which was developed by ROSATOM subsidiary OKB Gidropress. "*The VVER is a pressurized water reactor (PWR), the commonest type of nuclear reactor worldwide employing light water as coolant and moderator.*" (Rosatom, 2016).

The first of the VVERs to be constructed on a serial basis was VER-440 that has been operating in many countries like Bulgaria, Czech Republic, Finland, Hungary and Slovakia. The next generation is "…t*he VVER-1000 (V-320) that was a milestone not only in terms of generating capacity, but also because of the many safety innovations it incorporated. The VVER-1000 is the most common VVER design worldwide, 31 units are in operation."* (Rosatom, 2016).

Ukrainian nuclear power operator "Energoaton" provides all range of service for the acting NPPs but Russia still remains the main supplier of nuclear fuel and holder of spent fuel. One of the Strategy 2035 targets is to decrease dependency on Russia by diversification of energy suppliers (Strategy 2035, 2017: 44, 47).

In 2014 nuclear power operator "Energoatom" concluded the agreement with USA fuel supplier "Westinghouse" to involve new type of nuclear fuel TB3-WR at

Ukrainian NPPs. Currently “Westinghouse” nuclear fuel is used at Zaporizhia NPP and South Ukraine NPP (Energoatom, 2018). Also the construction of centralized spent nuclear fuel storage facility in Chernobyl zone that is provided by Holtec Company (USA) is planned to be finished in the end of 2019. Thus, Ukraine is going to refuse from Russian nuclear fuel in the near future and hold its spent fuel at its own territory.

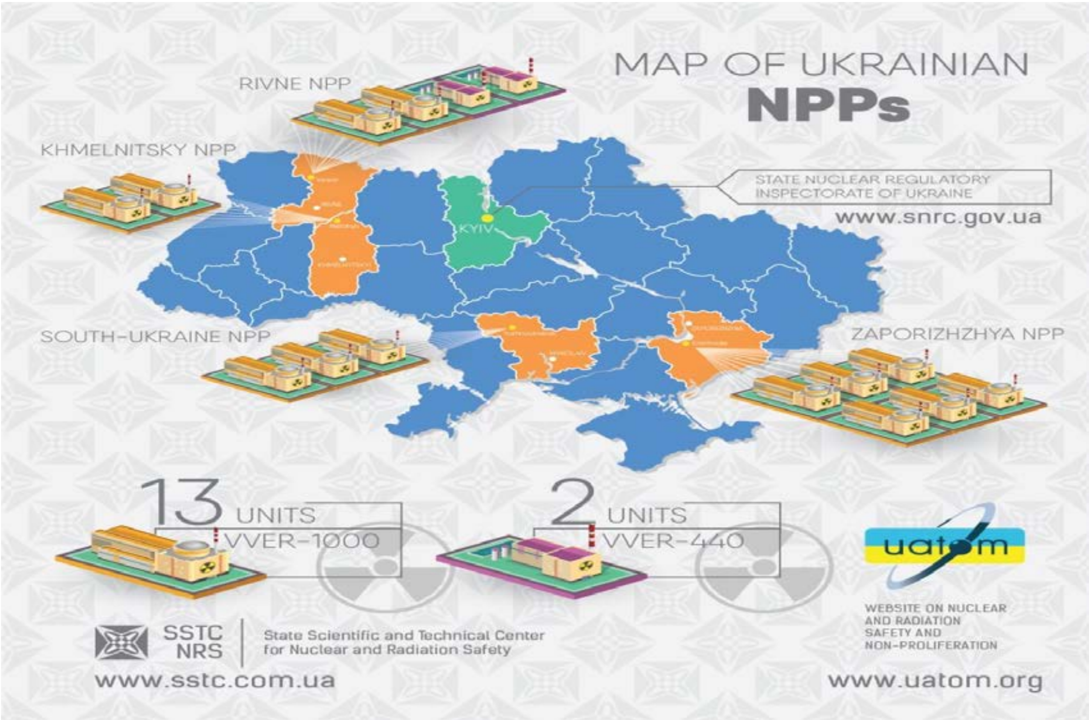


Fig. 2.2: Map of Ukrainian operating NPPs
Source: UAtom (2018)

As it was noted, power blocks No. 3 and No. 4 at Khmelnytskyi NPP with planned total installed capacity of 2 200 MW are under construction. The construction started in the 80s of 20^{th} century and has not been completed yet. In September 2015 Ukrainian Parliament denounced the agreement between Ukrainian and Russian Governments on the cooperation in construction of power units No. 3 and No. 4 at Khmelnytskyi NPP.

As of 2018 there is no final approval of design documents concerning completion of the construction of above mentioned power blocks and no new construction agreement with suppliers of nuclear power technology with corresponding source of funding has been confirmed either. The current feasibility study for the completion of Khmelnytskyi NPP power blocks envisages the use of VVER reactor manufactured by the only European supplier of VVER reactors technology - Czech company Skoda JS (Energoatom, 2018a). The feasibility study has not been fully approved by the Government because cooperation with Skoda JS, owned by Russian holding OMZ (owned by Gazprombank), is not possible due to economic sanctions imposed on Russian holding OMZ and Gazprombank by Ukraine[2] and by the U.S Department of Treasury[3].

But the possibility of involving a non-Russian ownership technology supplier could impose additional risks, as only two companies in the world have a proven record in VVER reactors construction: Skoda JS and Russian Atomstroyexport. In order to consider Chinese, USA or other potential suppliers, the design documentation has to be changed to allow the other types of reactor technology to be involved. Usage of other types of reactor technology could substantially increase the costs and time of the construction (Ecoaction, 2018).

However, Energoatom currently estimates the end of construction of these two blocks with installed capacity of 1100 MW each in 2026 after seven years from the commencing date with the total approved construction cost – EUR 2.3 billion (Energoatom, 2018a). But this term is very optimistic taking into consideration the long process of selecting technology supplier, securing funding, trans-border approval of the project documentation and the construction of power blocks that now are flooded with water for the last 30 years and thus the potentials of the said nuclear units are not clear (Diachyk et al., 2017: 24). At the same time taking into consideration low construction costs as a lot of preparatory work has been done, the commencement of these two nuclear power units could be ended till the end of 2030 (Nedashkovky, 2018).

Also most of the nuclear power capacities were installed in the 80s of 20th century with its exportation period of 30 years and are subject to prolongation for another 10 plus 10 or 20 years. Frequent stoppage and defaults as well as long maintenance periods of Ukrainian NPPs cause a low total capacity utilization factor for the last 8 years that vary from 66, 6% to 74, 5% and its development is shown in chart 2.2.

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[2] According to the Decision of the National Security and Defence Council of Ukraine as of May 2, 2018, OMZ and Gazprombank included in sanctions list for 3 years (no. 19 and 696).

[3] Subject to Directive 1 under Executive order 13662.

Thus average total capacity utilisation factor for the last 9 years is 71, 3%.

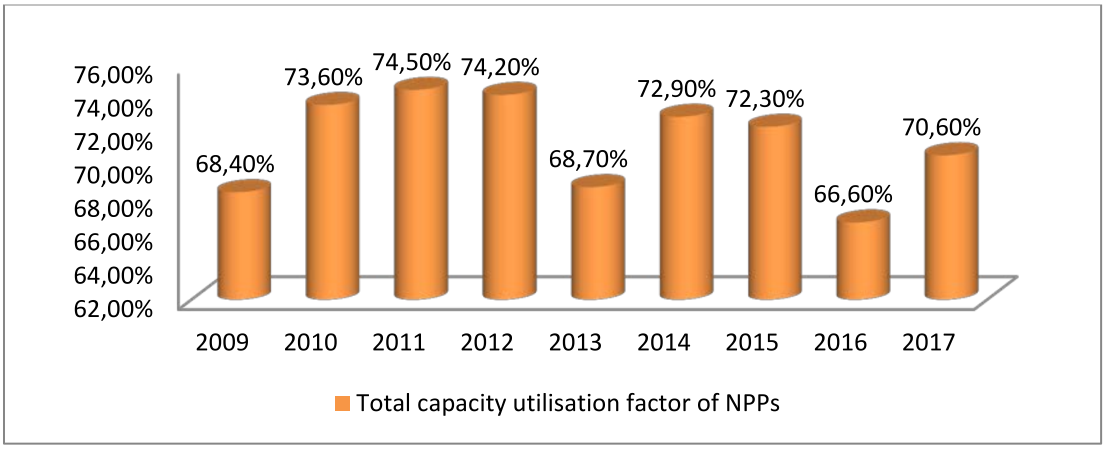


Chart 2.2: Total capacity utilisation factor of NPPs in Ukraine 2009 - 2017
Source: Energoatom (2018b)

Thus from the above mentioned data it is obvious that Ukrainian nuclear power is not effective due to low capacity utilization and most of its power blocks needs exceeded its design exploitation period. The question how many NPPs capacities should be replaced and when is answered in the chapter 3 after the presentation of solar PV power generation is given in paragraph below.

2.3 Solar PV power generation

The actual history of utility SPPs deployment in Ukraine started in 2011 with commencement of “Perovo” SPP with 105.56 MW power capacities in Crimea that for a shot time was one of the largest SPP in Europe. Unfortunately this SPP is no longer connected to Ukrainian electricity system. In 2012-2013 it was another peak of solar PV plants development generally in the southern regions of Ukraine (Odesa and Mykolaiv). During 2014-2015 it was a recession in SPPs development due to economic crises in Ukraine. Nowadays the situation is changing. Only in 2016-2017 it was commenced more than 300 MW capacities (chart 2.3) and solar PV generation attracts more and more investments in most of the regions of Ukraine that could be seen from the figure 2.3. Also figure 2.3 shows that absolute leader is the south Odesa region but the next place takes Vinitsa region with lower solar irradiation. But as of today under the data of National energy and utilities regulatory commission of Ukraine (NERC) the largest SPP with installed capacity of 53.4 MW (commenced in 2014) is situated in Mykolaiv region (NERC, 2018a).

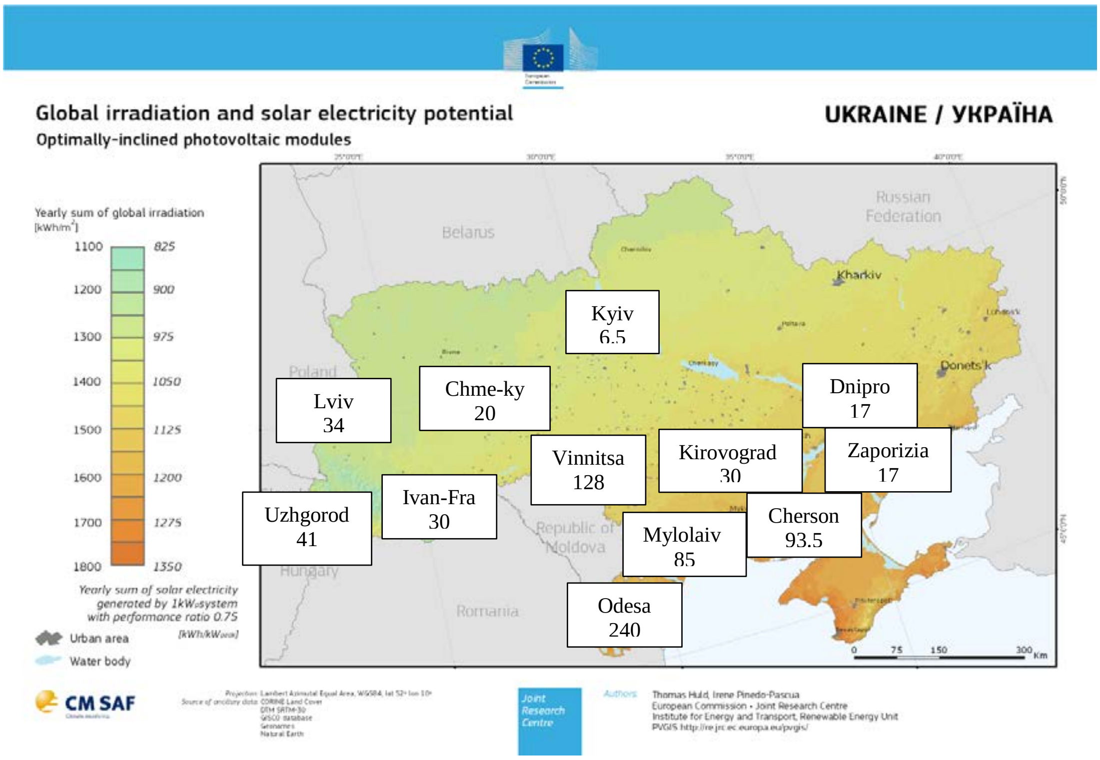
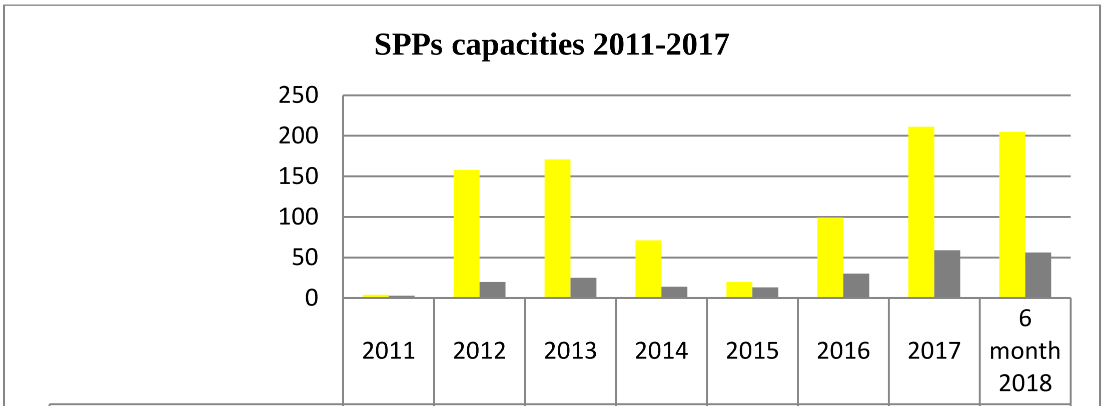


Fig. 2.3: SPPs capacities by regions in Ukraine (MW power)
Source: own calculations based on the data of NERC (2018a). Map: EC (2017).

Also NERC data evidence that in 2017 211 MW of SPPs capacities were installed that is two times more than in 2016 (NERC, 2017; 2018a). The share of SPPs in electricity generation balance of Ukraine was only 0.53 % in 2017 but the dynamic is positive (in 2016 – 36%) (SSS UA, 2018a).



	2011	2012	2013	2014	2015	2016	2017	6 month 2018
Installed capacity (MW)	4	158	171	71	20	99	211	205
Number of SPPs	3	20	25	14	13	30	59	56

Chart 2.3: SPPs installed capacity and number of SPPs[4].
Source: own calculation based on the data from NERC (2017; 2018a; 2018b)

[4] Installed capacity is given without solar PV capacities in Autonomous Republic of Crimea (ARC)

At the chart 2.4 it is shown that about 345 MW from total capacity comes to 13 SPP with installed capacity of more than 20 MW.

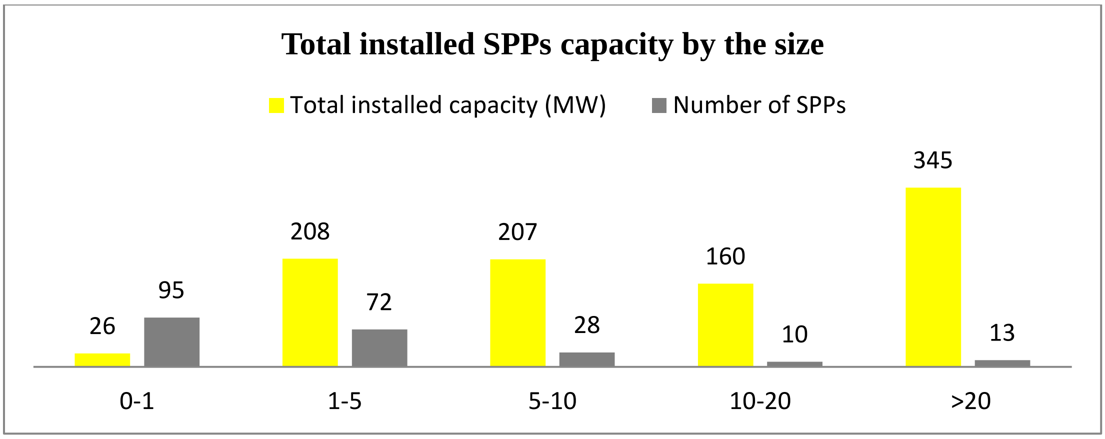


Chart 2.4: Total installed SPPS capacities in Ukraine y by the size
Source: own calculation based on the data from NERC (2018)

As of January 1, 2018 about 164 SPPs were installed in Ukraine with total installed capacity of about 742 MW and power production 714 million kWh (NERC, 2018a). SPPs power production in 2017 and 6 months 20018 is shown in table 2.4 below.

Table 2.4: Solar PV power production in 2017 and 6 months 2018

	Period	**Total installed capacity (MW)**	**Electricity generation (million kWh)**
1.	**2017**	742	714
2.	**2018 (6 month)**	947	499

Source: NERC (2018a, b)

It is also should be admitted that only during 6 month of 2018 it was installed 205 MW of new SPP capacities (NERC, 2018b) and during 8 month 2018 – 332 MW (NERC, 2018f). Thus for the last three years including 2018 the development of solar PV plants continues to rise with increase of capacities by 100 % each year to the previous year with average capacity utilisation factor of 13, 7% (NERC, 2018c).

2.4 Conclusions

Summarising data collection in this chapter it should be admitted that Ukraine electricity sector is strongly dependent on fossil fuels and in particular on nuclear power generation but at the same time nuclear power is not efficient and its units entered prolongation periods after expiration of their design terms. On the other hand solar PV shows 100% growth in capacities to the previous years. Thus in the chapter 3 the outlook of electricity demand in Ukraine till 2035 was assessed taking into consideration nuclear power phase out and in chapter 5 the utility scale solar PV plants cost competitive potential for covering possible electricity demand in Ukraine was discussed.

Chapter 3: Outlook for electricity demand in Ukraine in 2035

3.1 Outlook for electricity demand in Ukraine in 2035

This chapter is devoted to assessment electricity demand in Ukraine in 2035 taking into consideration the impact of NPPs phase out after 50 of exportation that include the prolongation of their lifecycle to 20 years.

As it was stated previously NPPs provided 55% of electricity in Ukraine in 2017. But this share of NPPs in the state electricity mix could decline significantly in 2035.

As it shown in Appendix 1 starting from 2030 till the end of 2035 4 835 MW of nuclear capacity expand its 50 years of exploitation. This reduction is associated with high capital expenses for the plant lifetime extension over 50 years and especially for the construction of new NPPs. At the same time till the end of 2030 two additional power blocks No. 3 and No. 4 at Khmelnytskyi NPP with installed capacities of 1 100 MW each could start its operation.

Thus the assumption of the development of the NPPs capacities and electricity generation is presented in charts 3.1 and 3.2. It was taken into consideration the construction of two power blocks at Khmelnytskyi NPP. The amount of estimated electricity generation was calculated taking into consideration average total capacity utilisation factor for the last 9 years of 71.3% (Yearly El. generation = total capacity*8760*capacity utilization factor [71.3%]).

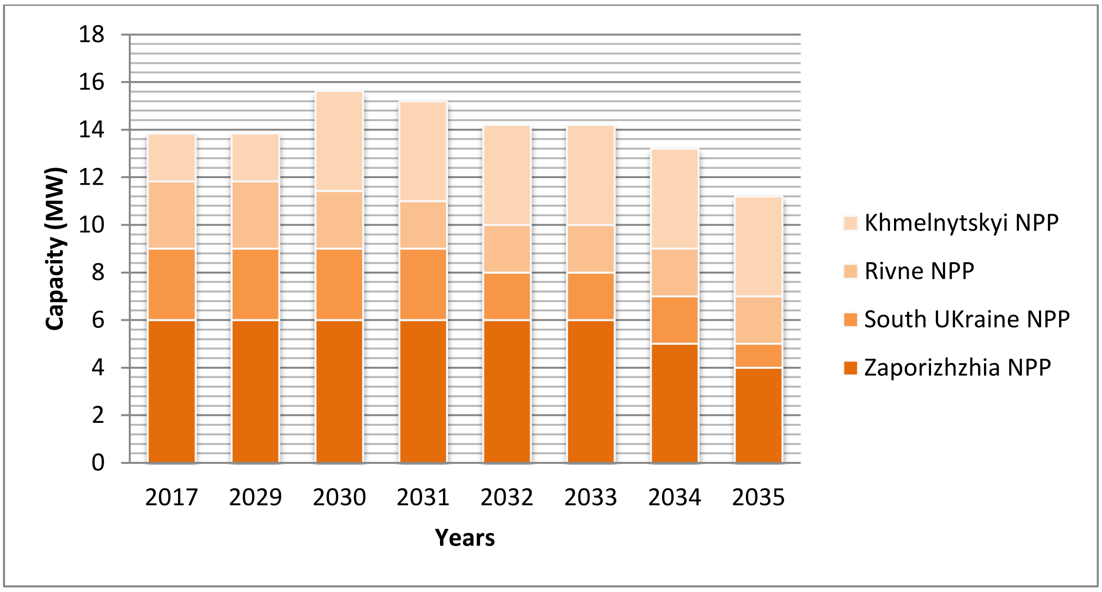


Chart 3.1: NNPs capacities development in Ukraine till 2035
Source: own calculations, UAtom (2018)

Charts 3.1 and 3.2 show that in 2034 installed capacity of all NPPs and power generation will start decline compared to 2017.

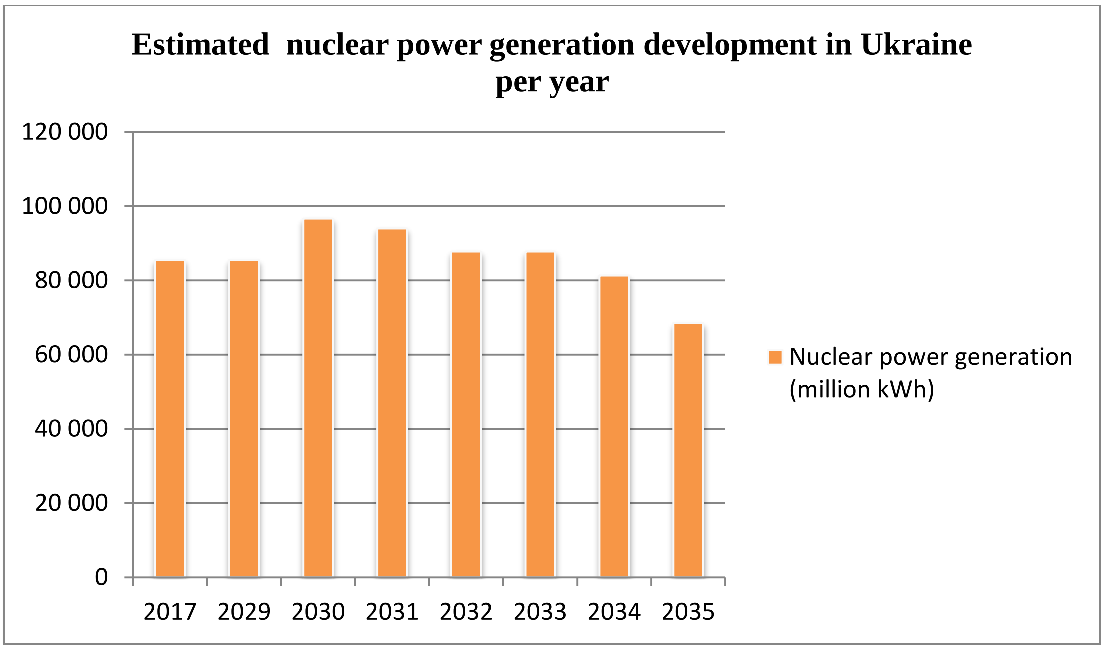


Chart 3.2: NNPs electricity generation development in Ukraine till 2035
Source: own calculation on the basis of UAtom (2018)

Abovementioned data demonstrate that at the best scenario which include the prolongation of licenses for all NPPs blocks to maximum technical secure term of exploitation of 50 years and end of construction of two power blocks at Khmelnytskyi NPP with installed capacity of 1 100 MW each, Ukraine should replace till the end of 2035 2 635 MW of phased out nuclear power capacity to new build electricity generation capacities with approximate yearly demand starting from 2035 of 16 450 million kWh (Estimated El. demand in 2035 [million kWh] = Phased out capacities [2635 MW] *8760*Capacity utilization factor [71.3%]).

It is also taken into consideration that population decrease and dramatic GDP drop in 2014-2016 years would not lead to increase of electricity demand in the near 15 years as well as transport electrification and household heating/cooling would be mitigated by energy efficiency measures.

As a conclusion it is estimated in this paper that in 2035 2 635 MW capacities that potentially could generating about 16 450 million kWh should be replaced with the same or other sources.

In the Strategy 2035 mentioned that from 2030 the process of NPPs phase out will start after 50 years of exploitation of NPPs and till 2020 Government should decide which sources of electricity generation should be appropriate for substitution of old NPPs. But still it’s declared that nuclear energy is worth utilization in Ukraine and its part in electricity generation balance should extend. Moreover it is stated that use of nuclear power inter alia by building new nuclear units could solve the issue of greenhouse emission and current Ukrainian government consider nuclear power as economically effective source of energy (Strategy 2035, 2017:16).

Although it is stated in the Strategy that further development of REN sources is a key target of its realization (Strategy 2017: 12) and the state policy should be oriented on promotion of commencement of SPPs (Strategy 2035, 2017: 48, 56).

3.2 Conclusions

Taking into consideration the assumption that electricity demand in Ukraine in 2035 will stay at the level of 2017, 2 635 MW nuclear power capacities that potentially could generate about 16 450 million kWh should be replaced with the same or other sources of power production.

To take well-grounded decision as to replacement of nuclear power by new nuclear units or other sources like solar PV power it is reasonable to make a look at nuclear power policies in EU, define the costs of new build NPP and within proposed boundaries of this paper define the cost of utility scale SPP that is done in paragraph 5.3.

Chapter 4: Nuclear power policies in EU

In this chapter nuclear power policies in EU were briefly presented with a view to determine the states were decision to phase out nuclear power was taken. It was also important to show on the existing examples weather PV solar power capable of replacing nuclear power.

For many decades nuclear power seemed to be economically feasible and important low-carbon source of energy. But firstly Chernobyl accident in 1986 and secondly Fukushima disaster in 2011 became imminent point for discussions and reverse policies in many European states causing three EU members (Belgium, Germany and Switzerland) took their decision to phase out nuclear power prematurely.
As could be seen from the table 4.1 for many EU states, the response to the nuclear accidents was more complicated and discussions are still going on over replacement of old reactors, commencement of new NPPs or phasing out acting nuclear units.

Table 4.1: Nuclear power policies in EU

Country	Policy	Planed capacity change
Austria	In 1970s the Zwentendorf NPP was built but has never produced power. In 1978 Austrian Parliament prohibited nuclear power generation till 1998 and in 1997 remain Austria anti-nuclear power state.	
Belgium	Under current legislation the nuclear power phase out should be completed by 2025.	5 913 MW phase-out by 2025
Bulgaria	Due to absence of source of financing the plans of lifetime prolongation of the existed nuclear power units are suspended.	
Czech. Rep.	National energy plan to 2060 assumes 50% nuclear capacity; however plans for two reactors are put on hold after the government refused to provide state support.	1200 MW in 2026 1200 MW in 2028
Finland	Two reactors planned.	1600 MW around 2020 1200 MW in 2024
France	Plans to reduce the share of electricity	

	from nuclear to 50% by 2025.	
Germany	Closed down 8 reactors in March 2011. Plans for complete phase-out by 2022.	8336 MW shut down in 2011. 12003 MW phase-out by 2022
Hungary	Two new nuclear power reactors are under construction.	1200 MW in 2023 1200 MW in after 2025
Italy	Phase-out all reactors in 1991.	
Lithuania	Two nuclear power reactors were closed in 2009.	
Netherlands	The decision on nuclear power phase-out was changed in 2006 but construction of new reactors is suspended due to economic reasons.	
Poland	Currently two nuclear power reactors are planned.	3000 MW in 2024 3000 MW in 2035
Romania	Two new reactors planned.	720 MW in 2019 720 MW in 2020
Slovakia	In the Energy Security Strategy as of 2008 the target of reaching 50% of power production from nuclear power is made.	1500 MW in by 2025
Spain	Remains political uncertainty concerning nuclear future due to removal of legal limitation to NPP prolongation lifetime over 40 years.	
Sweden	In 2010 cancelled phase-out plan from 1980 and plans replace old NPPs when decommissioned.	
Switzerland	In 2011 Parliament decided to phase-out nuclear power by 2034.	1102 MW phase-out by 2022 985 MW phase-out by 2030 1165 MW phase-out by 2034
United Kindom	Plans to reach the target of 16 000 MW of new NPP's capacity with several new units by 2030.	16 000 MW by 2030

Source: Aune, F. et el. (2015)

The example of positive nuclear policy in Eastern Europe is Hungary where new reactors are under construction. On the other hand Germany is a prominent example of preserving phase out policy accelerating this process after Fukushima accident. Another example is Belgium where the terms of realization of the decision to shut down of acting NPPs where postponed by the reason of absence of replacement capacities. The cases of Germany and Belgium are described below.

4.1 Nuclear phase out in Germany

Germany until March 2011 produced one-quarter of its electricity from nuclear energy (133 000 million kWh net in 2010) with acting 17 reactors. Now only seven reactors are in operation and produce 11.6 % while 37% of electricity comes from coal (Morris & Pehnt, 2017: 22).

Table 4.2 shows that in 2017 power plants using coal and gas generate more electricity than NPPs and renewables. But at the same time WPPs and SPPs generated more electricity than NPPs.

Table 4.2: German power plants capacity and electricity production in 2017

Source of electricity generation	Power plants capacity, MW	Electricity generation, million kWh	Electricity generation per capita kWh
Coal and gas	75 840	328 200	3 970
Hydro	5 600	19 700	238
Nuclear	10 800	75 900	918
Biomass	7 380	45 500	550
Wind	56 180	105 500	1276
Solar	42 980	39 800	481
Others	1 200	39 006	471
Total	200	654 200	7913

Source: Fraunhofer (2018)

These numbers confirms that the nuclear phase-out is a central part of Germany's Energiewende policy that grounds on the view that nuclear power is unexpectedly risky, expensive, and in many aspects incompatible with REN sources. As could be seen from the Chart 4.1 in 2022, the last nuclear plant in Germany is to be shut down (Morris & Pehnt, 2017: 23).

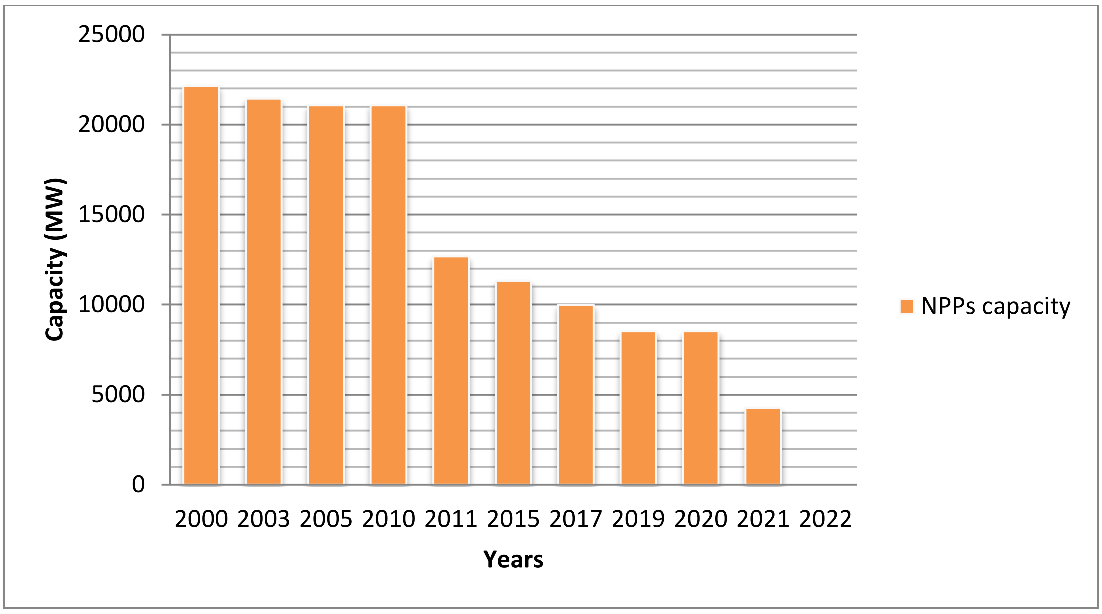


Chart 4.1: Germany nuclear phase out plan till 2022
Source: Morris & Pehnt (2017)

Germany is going to replace nuclear power with electricity from renewable sources that are mostly solar, onshore and offshore wind power, "… *power from gas turbines, lower power consumption (efficiency and conservation), demand management, and – in the interim – the rest of its existing fleet of coal power plants.*" (Morris and Pehnt 2017: 23).

Table 4.3**:** German nuclear capacities replacement 2011-2022

<table>
<tr><td colspan="5">20 900 MW of nuclear capacity</td></tr>
<tr><td>NPPs phase out in 2011</td><td colspan="2">NPPs phase out 2011-2015</td><td colspan="2">NPPs phase out 2015-2020</td></tr>
<tr><td>8 400 MW</td><td colspan="2">-</td><td colspan="2">12 500 MW</td></tr>
<tr><td>Germany has more reserve capacity than needed for the phase out of eight NPPs in 2011</td><td colspan="2">From 2011-2015, no NPPs close, but 6 500 MW other capacity added</td><td colspan="2">By 2020 Germany will have added 3 800 MW more than is needed by 2022 to replace its nuclear fleet</td></tr>
<tr><td>Available reserve capacity</td><td>New REN</td><td>New other plants</td><td>New REN and gas</td><td>DSM[5]</td></tr>
<tr><td>11 200 MW</td><td>3 700 MW</td><td>2 800 MW</td><td>5 000 MW</td><td>2 000 MW</td></tr>
<tr><td colspan="5">… to be replaced by 24 700 MW</td></tr>
</table>

Source: Morris & Pehnt (2017)

[5] Demand side management

Table 4.1 shows that Germany is replacing its nuclear power by mix of measures with substantial role of REN sources and basically wind and solar.
In 2017 SPPs generated about 40 million kWh (Wirth, 2018: 5) and covered approximately 7.2 % of Germany's net electricity consumption including grid losses in 2017. And it should be taken into account that Germany has not high solar irradiation thus SPPs generate around 950 MWh/ per 1 MW installed power capacity. Thus in 2017 on sunny days solar PV power generation in Germany could reach 35% of the peak electricity demand and on weekends and holidays even more up to 50% (Wirth, 2018: 5, 41).
The German Renewable Energy Act EEG as of 2017 envisages the yearly installation of 2 500 MW solar PV capacities (Wirth 2017: 5). Despite this target only 1 750 MW of new solar PV capacities were installed in Germany in 2017 although these solar PV capacities correspond to 2% of total new solar PV capacities that were installed in the world in 2017 (Wirth 2017: 5).
It should be also noted that "*On the shortest day of 2016, Germany's installed PV capacity still managed to produce around 7 million KWh - as much power as five large nuclear reactors - for two hours, thereby helping to offset peak demand for power*." (Morris and Pehnt 2017: 71).

Summarizing above-mentioned facts it is clear that PV solar power generates 481 kWh per capita and plays significant role in Germany that leaving nuclear power age behind. The German example demonstrate another conclusion that nuclear power replacement could be done within the wide range of measures and sources and what is more important that this process does not exclude the increase of fossil fuel in such as coal and gas in electricity mix that provide main flexible capacities at list for a midterm perspective. And the most important thing is that nuclear power base load restrains acceleration of REN sources development.

4.2 Nuclear phase out in Belgium

Belgium is one more state that took a decision to phase-out nuclear power. But unlike Germany the end of this process was terminated several times. Without own fossil fuel extraction Belgium strongly rely on electricity import and nuclear power generation. As could be seen from table 4.4 electricity production in Belgium was about 85 520 million kWh in 2016 with 43 520 million kWh from nuclear power.

Table 4.4 also shows that NPPs generate in Belgium about 50% of its electricity and thus nuclear power remains the main energy source for electricity generation with its seven reactors in operation (more details concerning Belgium NPPs could be found in Appendix 2).

Table 4.4: Belgium power plants capacity and electricity production in 2016

Source of electricity generation	Power plants capacity, MW	Electricity generation, million kWh	Electricity generation per capita kWh
Coal and gas	8 540	31 470	2773
Hydro	1 430	1 490	131
Nuclear	5 910	43 520	3834
Wind	2 370	5 440	479
Solar	3 425	2 945	259
Others	224	514	45
Total	**21 560**	**85 520**	**7535**

Source: IAEA (2018)

Notwithstanding the nuclear power dependency, in 2003 the Belgian Federal Parliament adopted the law prohibiting construction of new NPPs and limiting the lifetime of the existing NPP units to 40 years. According to this law, nuclear power units are to be phased out from 2015 till 2025. In order to satisfy the power demand, next elected Parliament fully postponed the nuclear power phase out by 2025 (IAEA 2018).

The nuclear phase out schedule in Belgium is shown at chart 4.2.

In the future, it is planned that the decommissioned nuclear plants should be replaced by new combined cycle gas turbines and increase from 3 500 to 6 500 MW import capacity from Germany, the Netherlands and the United Kingdom. It also plans to integrate more renewable energy, including 2 300 MW of offshore wind (IAEA, 2018).

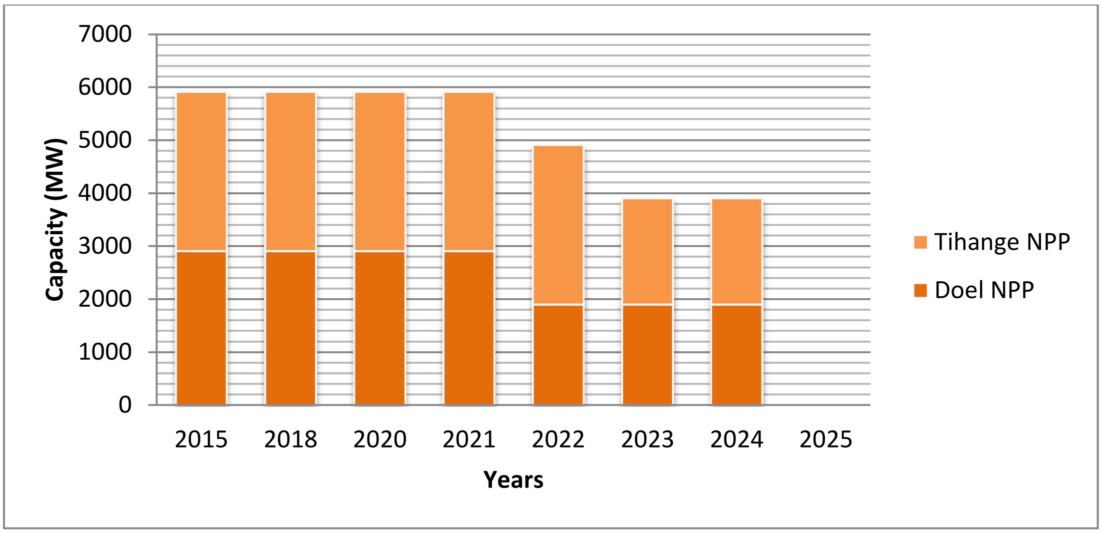


Chart 4.2: Belgium nuclear phase out plan till 2025
Source: IAEA (2018)

Thus Belgium in its plans to phase out nuclear power also relays on renewable sources and in particular on offshore wind power. PV solar power market is more residential than utility scale and no attractive development is in place.

4.3 Comparison of nuclear and solar PV power generation in Ukraine, Germany and Belgium

Currently Ukraine, Germany and Belgium are members of *nuclear power generation club* but all three countries have different approaches towards nuclear power phase out policy. While Germany could easily replace its nuclear capacities with gas and REN sources by planned term - 2022, Belgium always postpone its nuclear power phase out decision being unable to replace nuclear power capacities with alternative power generation sources. Thus the political decision on nuclear power phase out could be successively implemented if only economic and technical feasibility analysis is done retrospectively, otherwise the only option could be to import electricity. On the other hand all previous and current Ukrainian governments used to consider the nuclear power as cheap and reliable source of energy and despite Chernobyl accident, there are no plans in Ukraine to phase out nuclear power before nuclear reactors will reach their maximum operation term of 50 years.

Solar PV power production could be one of the possible sources to help with nuclear power phase out and replacement as in Germany, where half of nuclear power production was produced by solar PV in 2017, and Belgium or nuclear power replacement as in Ukraine.

Table 4.5 shows that solar PV power production in Germany and Belgium exceeds Ukrainian values in many times although Ukraine has higher solar irradiation and more territory appropriate for utility scale SPP deployment.

Table 4.5: Comparison of nuclear and solar PV power generation in Ukraine, Germany and Belgium

	Ukraine (2017)		**Germany (2017)**		**Belgium (2016)**	
Source of electricity generation	**Nuclear**	**Solar**	**Nuclear**	**Solar**	**Nuclear**	**Solar**
Power plants capacity, MW	13 835	742	10 800	42 980	5 910	3 425
Electricity generation, million kWh	85 586	714	75 900	39 800	43 520	2 945
Electricity generation per capita kWh	2 234	18	918	481	3 834	259

Source: own table on the basis of tables: 2.2, 4.2 and 4.4

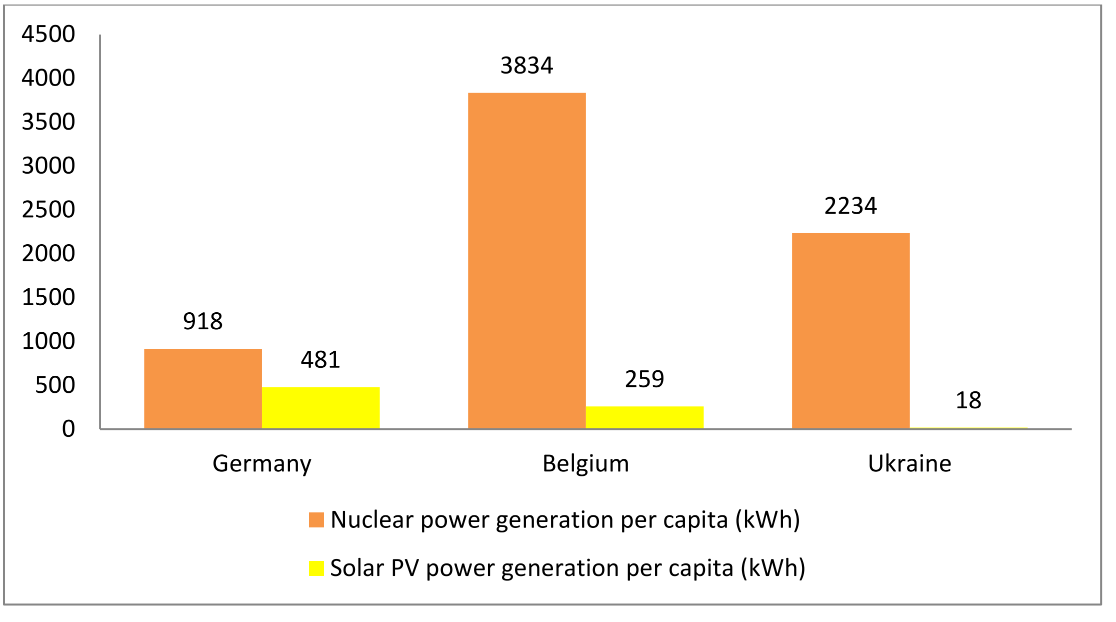


Chart 4.3: Nuclear and Solar PV power generation per capita in Germany Belgium, and Ukraine
Source: own chart on the basis of table 4.5

Nevertheless chart 4.3 shows insignificantly small share of solar PV power generation in Ukraine comparing to the EU states that took decision to phase out nuclear power. In particular in Germany nuclear power generation exceed solar PV power generation in 2 times; in Belgium – 15 times and in Ukraine – 124 times. These comparison shows that Ukraine has great potential for solar PV development.

4.4 Conclusions

The German and Belgium nuclear power phase out cases show that solar PV power along is not currently capable of fully replacing nuclear power but only may reduce its use. Long winter nights, when power consumption is at a maximum and at the same time no solar PV power is available, present the most dramatic challenge. Thus the revolutionary expansion of solar PV could be possible when substantial amount of storage capacities would be available. Despite this, PV solar power is increasingly colliding with conventional power plants (NPPs) with slow start-up and shut-down processes (Wirth 2017: 48). "*These power plants, which are almost only capable of covering the base load, must be replaced by renewables and flexible power plants as quick as possible.*" (Wirth 2017: 48).

Chapter 5: Nuclear and solar PV power cost comparison

As it was shown in chapter 3 the demand of electricity supply in Ukraine might increase in 2035 by 16 450 million kWh due to 2 635 MW capacities of nuclear power units would expand its term of exploitation. This could be a real challenge for renewables and partly for PV solar power to occupy this niche. This opportunity is confirmed by Germany where PV systems play significant role in nuclear power replacement. But a comprehensive proposal for replacement of nuclear power by solar PV power in Ukraine should be done only after comparison of costs for new build power capacities, defining solar PV potential barriers for solar PV deployment.

5.1 Method of approach

When comparing electricity generation sources and technologies it is recommended that economic feasibility of such sources to be evaluated. For this reason the levelized cost of electricity (LCOE) generation method is possible to use (Branker et al., 2011:2).

It should be noted that "… *the LCOE methodology is an abstraction from reality and is used as a benchmarking or ranking tool to assess the cost-effectiveness of different energy generation technologies. The abstraction is made to remove biases between the technologies*". (Branker et al., 2011:3).

The method considers the lifetime of generation' system and costs to estimate a price per unit power generated (Branker et al., 2011:3).

Thus the main assumptions that should be considered in LCOE methodology to compare nuclear and solar PV power are: average nuclear and solar PV plant price, the evaluation of discount rate (WACC), investment system lifetime and degradation of solar PV system over considered lifetime (Branker et al., 2011:6).

In this chapter for the purpose of comparison nuclear power technology to solar PV power, the current LCOE levels are given from the open resources and the calculation method of LCOE for further solar PV development is given in chapter 8.

5.2 Outlook for nuclear power costs

Most of the nuclear power capacities in Ukraine were installed in the 80s of 20th century. Currently power production cost by NPPs in Ukraine amounted to EUR 20 /MWh (Energoatom, 2018b) although investment costs are not taken into consideration. For the replacement of old nuclear power capacities with new build NPPs the investment costs need to be defining for the purpose of calculation full nuclear power electricity costs.

As it is shown in chart 5.1, in 2034 end 2035 the electricity demand could increase rapidly that is caused by phase out of five nuclear power blocks from 2030 till 2035 with installed capacity of 4835 MW and it is advisable that the decision to overcome this challenge and to cover drop in electricity supply should be taken in the near years. In July 2018 Ukrainian government supported previous intentions to continue construction of two NPPs blocks with total installed capacity of 2200 MW power at Khmelnitsky NPP. As it was stated in paragraph 2.2 the construction of these additional nuclear power capacities could be ended by 2030. Thus only 2635 MW nuclear power capacities with yearly estimated power generation of 16 450 million kWh still should be replaced in 2035.

To make outlook at the economic feasibility of nuclear power in Ukraine, current cost of new build NPPs should be considered. Current external cost of new build NPPs are presented below as the last nuclear power unit in Ukraine was commenced in 2004.

For a large reactor with a power rating of 1 000 MW or greater, the capital cost regards from EUR 3.5 to 7.9 million/MW depending on reactor design, financing conditions, the regulatory process and construction time (Ferguson, 2011: 411).

According to the estimation of Ukrainian NNEGC “Energoatom”, the cost of power units construction at new units is EUR 6.5 million /MW (Energoatom, 2016).

The cost of new nuclear power plants construction is growing every year. For example, the construction of new NPP power units of the EPR type (European Pressurized Reactor) with a capacity of 1 670 MW in Flamanville (France) is estimated at EUR 6.28 million /MW (Lifegate, 2018).

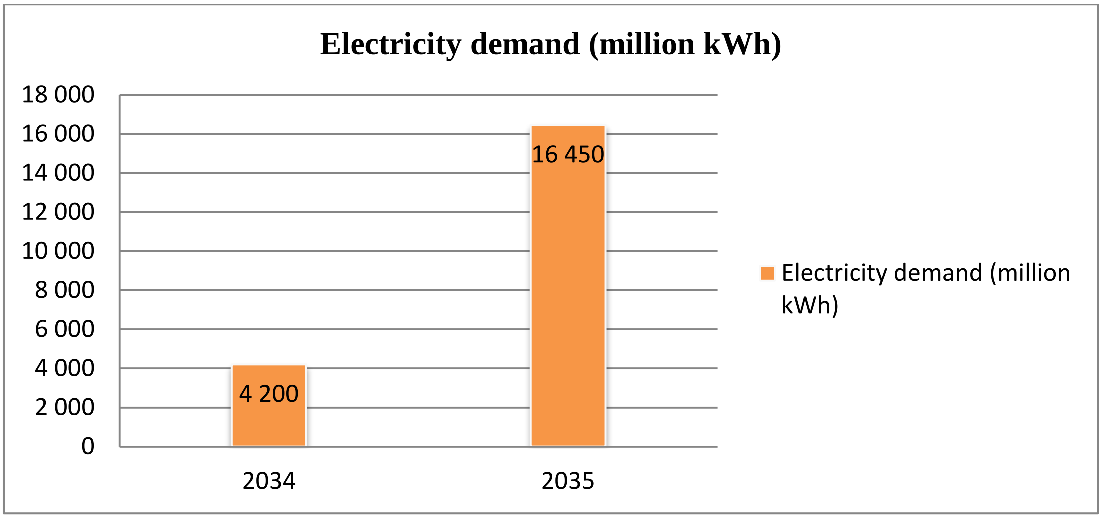


Chart 5.1: Estimated yearly estimated electricity demand in Ukraine (million kWh)
Source: own calculation

The joint study of the International Energy Agency (IEA), the Nuclear Energy Agency and the Organization for Economic Cooperation and Development (OECD) indicates that the cost of construction of new NPP power units in European countries is from EUR 4.64 million/MW in Slovakia to EUR 7 million/MW in Hungary (IEA-NEA, 2015). Thus, the cost of construction in Hungary is comparable to the estimates of the NNEGC "Energoatom". Taking into account discussed above data and the fact that construction costs are constantly growing due to the increased safety requirements for operation of NPPs, data of the NNEGC "Energoatom" could be taken into account for the long-term modeling of the energy sector development in Ukraine (Diachuk et al. 2017: 24).

Thus it could be estimated that the price of construction of new NPP block with 1000 MW capacities in Ukraine could amounted to EUR 6.5 million/MW of installed capacity.

The cost of extending the life time of operating NPP units for 20 years will be (~ EUR 0.46 million/MW of installed capacity (Diachuk et al. 2017: 24).

For the comparison purposes nuclear power long time generation costs or LCOE should be evaluated.

"*LCOE depends on the number of units installed at a site, location, capital cost, interest rate and capacity factor (actual average power output divided by rated power)*" (Diesendorf, 2016a). LCOE estimates for nuclear are EUR 98/MWh based on pre-2014 data from the IPCC that does not include subsidies (Diesendorf, 2016a) and EUR 97-159/MWh based on 2017 data from multinational financial consultants Lazard that excludes US federal government loan guaranties and subsidies and decommissioning (Lazard, 2017: 2).

One more example is the construction of Hinkley Point NPP in England that is planned to go into operation in 2025. The planned cost of power production has been increased with years, and currently amounted to EURO 120/MWh without inflation for a period of 35 years (Wirth, 2017: 10).

The mutual study of International Energy Agency and Nuclear Energy Agency as of 2015 “Projected costs of Generating electricity” also presented estimated LCOE in different European countries. The cost of electricity generation of new build units estimates from EUR 101 to 120/MWh at 10% discount rate (Table: 5.1).

Table 5.1: Projected nuclear LCOE costs for NPPs build 2015-2020 (EUR/MWh)

Country	LCOE at 10% discount rate (WACC)
Belgium	101
Hungary	108
Japan	102
Slovakia	101
UK	120
Average	**106**

Source: IEA-NEA (2015: 49)

As it was noted previously all NPPs in Ukraine are state owned and nuclear power generation under current legislation can’t be in privet property. Thus financing of new NPP could be done only by state or by attracting foreign public or private financing under state guaranty. The public source of nuclear power financing or state loans guaranties could definitely decrease cost of capital but high risks due to unstable political situation in Ukraine will not allow reduce WACC lower than 10%.

For the average LCOE assumption in this paper Slovakia is taken as lowest border and UK as a highest. Both states have significantly more stable finance situation and thus lower WACC but in Ukraine value of labour is much lower than in the UK that substantially influences investment costs and O&M costs as well as centralized spent nuclear fuel storage facility in Chernobyl zone that is now under construction should be also considered as a factor that minimizing operational costs. Also despite nuclear power reactors are not manufactured in Ukraine, other 70% of NPP construction costs such as generators and power turbines are produced domestically.

Thus for Ukraine with high rate of WACC (10%) due to high risks caused by unstable political situation the LCOE is taken for the purpose of this paper at the average level of EUR 106 /MWh for new NPP in Ukraine and investment costs EUR 6.5 million/MW of installed capacity.

Thus the nuclear power production requires long period of construction, solid investments and at the example Hinkley Point NPP in England can't be fully calculated at the start of the project.

5.3 Outlook for solar PV power costs in Ukraine

PV solar power along with wind power is one of the most promising renewable sources of electricity generation in Ukraine. The whole territory of Ukraine is a zone of relatively high solar activity. As it is stated in National action plan on renewable energy till 2020 adopted by Ukrainian Government in October 2014 the average yearly solar insolation in Ukraine shifting from 1070 kWh on one square meter in the Northern part of the country and 1400 kWh or higher in the Southern part of Ukraine (National Action Plan, 2014).

In Ukraine SPP could be operated during the whole year but the highest efficiency is reached from April till October in the South and from May till September in the North of the country. More visually PV solar power potential could be seen at map that is presented at figure 5.1.

Above presented solar resource map displays solar PV production potential in Ukraine. *"It represents the average daily / yearly sum of electricity production from a 1 kW-peak grid-connected solar PV power plant, calculated for a period of 22 recent years (1994-2015). The PV system configuration consists of ground-based, free-standing structures with crystalline-silicon PV modules mounted at a fixed position, with optimum tilt to maximize yearly energy yield."* (The World Bank, 2017).

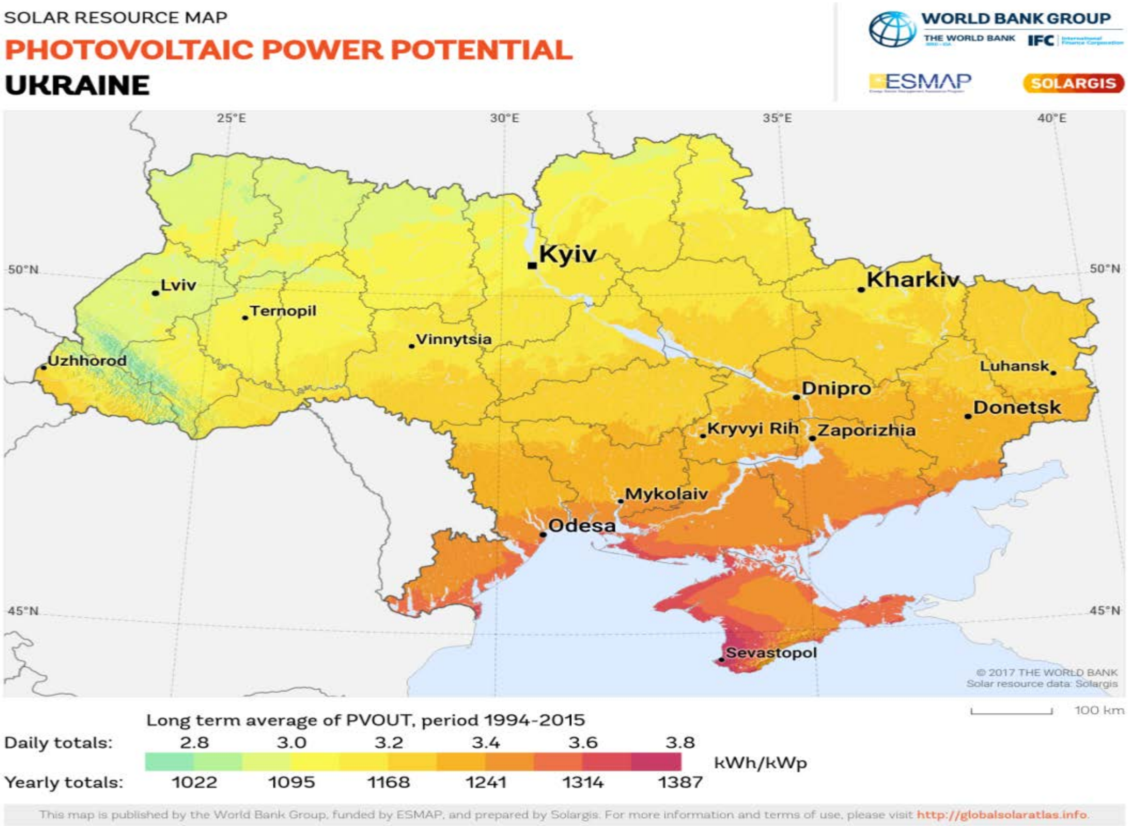


Fig. 5.1: Photovoltaic Electricity Potential of Ukraine
Source: The World Bank (2017)

The optimum tilt ranges from 32 to 39 towards the equator. The solar power calculation is based on high-resolution solar resource date and PV modeling software provided by Solargis. To simulate power losses in the solar PV power plant, solar irradiation, air temperature, ground temperature, soiling and snow as well as losses in cables, inverters and transformers were taken into consideration in calculations at the level of 9%. The solar PV power plant availability is considered to be 100%.The solar resource database is calculated from atmospheric and satellite data with a 15-minute and 30-minute time step and a spatial resolution of 1 km. (The World Bank, 2017).

Average potential of solar energy in Ukraine is 1200 MWh /MWp with 85% performance ratio (Vosniak, 2010: 2) and is higher than in Germany - 1190 MWh /MWp (Fraunhofer ISE, 2015: 53) and average utilisation capacity factor is 13.7% (NERC, 2018c).

According to the National action plan on renewable energy till 2020 adopted by Ukrainian Government in October 2014 the preferred installed capacity of SPPs in Ukraine estimated at the level of 4 000 MW (National Action Plan, 2014).

At the same time according to the State Agency on Energy Efficiency and Energy Saving of Ukraine, the theoretically possible potential of solar energy at the territory of Ukraine is over 730 000 million kWh per year but the technically possible potential for utility scale SPPs is only 34 200 million kWh per year (SAEE, 2015). One of the main obstacles to the intensive development of solar power installations is a poorly developed grid and outdated centralized electricity control over the demand.

Although under the estimations that were made by International Renewable Energy Agency in 2017 a further potential for solar PV up to 70 000 MW can be unlocked by 2030 if more stable frameworks are provided (IRENA, 2017: 55) (Table: 5.2).

Table 5.2: Potential of Solar PV power in Ukraine

Technology	**Additional cost-competitive potential**		**Technical potential**	
	MW	**Million kWh**	**MW**	**Million kWh**
Solar PV	53 264 – 69 785	67 655 – 87 451	70 611	88 370

Source: IRENA (2017)

Under the opinions of the market players' investment costs amounted from EUR 0.8million/MW to 0.85 million/MW power for SPP with 20 MW power capacity and operating costs EUR 5 000/MW installed capacity (Terce, 2018). In the case of attraction of foreign investments such as European financial institutions or Chinese state banks the effective interest rate is 12% (debt rate including risks) and equity rate in Ukraine is 8% in EUR and WACC that also includes country risks amounted to 11 % and LCOE EUR 94-99 MWh (Terce, 2018).

At the same time LCOE costs for utility SPP in Ukraine with investment horizon of 20 years are calculated by NERC in 2018 and presented in table 5.3. Under opinion of state regulator, current (2017) capital costs in Ukraine amounted to EUR 800 000 /MW power, WACC 20%, SPP economic lifetime 20 years and LCOE EUR 132.4 MWh.

Table 5.3: SPP LCOE costs in Ukraine

System costs. EUR /MW power	LCOE Euro/MWh				
	Weighted average cost of capital (WACC) rate				
	10 %	**12%**	**15%**	**18%**	**20%**
700 000	68,6	77,5	91,6	106,2	116,3
720 000	70,4	79,6	94,1	109,2	119,5
800 000	79,9	88,1	104,2	121	132,4
900 000	102	104	119	136	150

Source: NERC (2018c)

It should be also admitted that in accordance to Current and Future Cost of Photovoltaic study that was presented by Fraunhofer ISE in 2015, investment cost of solar PV power plants until 2050, will decrease dramatically as shown in the table: 5.4 below.

Table 5.4: Average estimated investment cost reduction of solar PV power plants till 2035

Investment cost solar PV (turnkey cost)	2020	2025	2030	2035	Average reduction per year
Average value EUR /MW	823 000	724 000	651 000	583 000	16 000

Source: Fraunhofer ISE (2015)

Summarising above mentioned findings it could be taken into consideration for the purposes of this paper that Ukraine has cost competitive potential to replace with PV solar power generation yearly at least 67 million kWh with 53 MW capacities by 2030. For the aims of this paper taking into consideration the data from state regulator (NERC) and market experts (Terce M.) the investment costs in 2018 for utility scale SPP are taken at about EUR 0.85 million/MW with a view of its yearly reduction by EUR 16 000/MW till 2035 and LCOE in 2018 at EUR 99 /MWh that is strongly dependent on the WACC rate and investment costs. This rate of LCOE also as of 2018 is also proven by calculations done also in chapter 8 and appendix 3.

5.4 Cost comparison of solar PV with nuclear power generation

The comparison method of costs and merely LCOE between two sources of generation could give the answer weather solar PV cost competitive with nuclear power and could replace its capacities. It should be at once admitted that solar PV and nuclear power have different capacity utilization factor. It is estimated in this paper that average capacity utilization factor for solar PV is 13.7% (NERC, 2018c) and average total capacity utilization factor for NPPs is 71.3% (Energoatom, 2018b). Table 5.5 shows that 1 MW nuclear power capacity could be replaced with 5.2 MW solar PV power capacities regarding yearly generation of the same amount of electricity.

Table 5.5: Capacity utilization factor for solar PV and nuclear power in Ukraine

Average total capacity utilization factor for NPPs (%)	**Average capacity utilization factor for solar PV (%)**	**Ratio of capacities of nuclear to PV power**
71,3	13,7	5.2

Source: NERC (2018c) and ENERGOATON (2018b)

Based on the collected data costs that was collected previously table 5.6 summarise and presents the cost comparison for deployment of abovementioned two sources of electricity generation in Ukraine in current estimated prices.

Table 5.6: Cost comparison of PV solar with nuclear power generation in Ukraine

	NPP	**SPP**
Investment costs million EUR/MW power	6.5	0.85
Power production per 1 MW installed capacity (MWh)	6 246	1200
Average LCOE EUR/MWh	106	99

Source: own calculations

Table 5.6 shows that LCOE for new build utility-scale SPP of 20 MW installed capacity and new build NPP of 1 000 MW installed capacity are within 10% deviation range but the construction cost differ dramatically. Replacement of 1 MW nuclear power capacity with nuclear power amounted to EUR 6.5 million and with solar PV EUR 4.42 million taking into consideration capacities ratio (0.85*5.2=4.42).

As it was discussed in chapter 3 the gap in electricity demand in 2035 could be amounted to 16 450 million kWh. Taking into consideration above mentioned data of solar potential in Ukraine, current state of the art in the solar PV technology efficiency development and current prices for solar PV systems, this demand could be theoretically covered by 13 700 MW of installed capacity of solar PV power (2 635 (phase out nuclear power capacities in 2035) *5.2 (PV to nuclear capacities ratio)).

Thus to replace 2 635 MW nuclear capacities with new build NPPs Ukraine needs EUR 17 billion and with solar PV plants EUR 11,6 billion in current prices of 2018. One more factor that could be in favour for solar PV is the construction time of SPP. Theoretically, SPP with total installed capacity of 1 000 MW could be installed and connected during several years in Ukraine, while new build 1 000 MW NPP needs at least 10 years to be connected to the grid.

It should be also noted that "…w*orld has only a few decades of high-grade uranium ore reserves left. As the ore-grade inevitably declines, the fossil fuel used to mine (with diesel fuel) and mill uranium increases and so do the resulting greenhouse gas (GHG) emissions. When low-grade uranium ore is used, the life-cycle GHG emissions will increase to 131 g/kWh. Only if mining low-grade ore were done with renewable fuel, or if fast breeder reactors replaced burner reactors, could nuclear GHG emissions be kept to an acceptable level, but neither of these conditions is likely to be met for decades at least*" (Diesendorf, 2016a).

Thus today it's more economically feasible to invest in PV than in nuclear power.

5.5 Conclusions

Summarizing collected data it is obvious that nuclear energy is cheap only if not taking into consideration capital expenses. As it is shown in table 5.7 high investment costs of nuclear power makes it uncompetitive with solar PV in Ukraine.

Table 5.7: Effective cost comparison of nuclear power replacement of 16 450 million kWh with nuclear and solar PV power in 2035

	Nuclear power	**Solar PV power**
Investment costs of 1 MW power capacities (EUR/MW)	6.5 million	0.85 million
Capacities needed to replace 2 635 MW of nuclear power in 2035	2 635	13 700
Replacement costs of 2635 MW nuclear power capacities (EUR/MW)	17 727 million	11 646 million
Average LCOE EUR/MWh in 2018	106	99

Source: own table on the basis of tables 5.5 and 5.6

Thus new build nuclear units become more and more expensive, with GHG emitting life cycle and not flexible in the era of digitalization in electricity management of demand and supply and it is not recommended to invest money in expansive nuclear power technologies supporting their producers.

Replacement of nuclear power with solar PV could significantly influence the value of solar PV generation per capita in Ukraine in 2035 presented in chart 5.2 and reach current German value in the case of 16 450 million kWh of nuclear power replacement and Belgium - in the case of 8 166 million kWh replacement with solar PV (for German and Belgium value of solar PV generation per capita see chart 4.3).

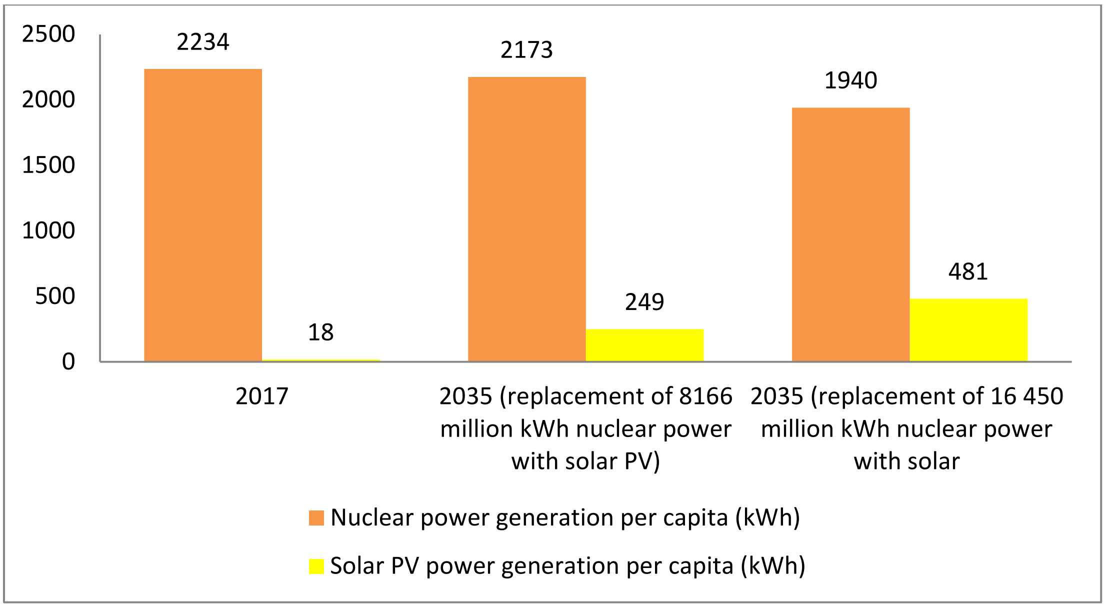


Chart 5.2: Scenarios for nuclear and solar PV power generation per capita in Ukraine in 2035
Source: own chart on the basis of table 2.2 and UN data[6]

In chapter 6 it is discussed whether the possibility of replacement in 2035 of 16 450 million kWh generated by NPP with solar PV correspond to market and economic conditions in Ukraine.

[6] Under United Nations "World population prospects" 2017 revision, Ukrainian population could decrease by 0.5% each year till 2050

Chapter 6: Barriers to utility scale solar PV deployment in Ukraine

To evaluate the potential of solar PV capacities that could be de-facto replaced by cost competitive solar PV power market, technical and economic barriers are analysed below.

6.1 Barriers to utility scale solar PV deployment in Ukraine

Market and technical barriers

First of all it should be admitted that under official information of Power transmission operator Ukrenergo that is shown at figure 6.1 electricity generation in peak load in midday at longest day of the year hardly exceed 17 million kWh when solar PV production could be at maximum levels. At the same time the share of nuclear power amounted to 9-10 million kWh and would not be lower than 8 million kWh ((13 835-2635MW)*71.3%*1000) in 2035 in the case of partly nuclear power replacement. The reduce of power generation in nuclear plants is not economically reasonable as nuclear power being a base load power in Ukraine can't balance electricity demand. "*NPPs are technically able to run with a power gradient of up to 2% min. and a power increment from 50% to 100%*" (Ludwig et al., 2010, cited by Wirth, 2018: 36). Thus taking the assumption that was made in this paper that power demand would be constant in 2035 as in 2017, the remained electricity generation in peak load in summer month would be amounted to 9.5 million kWh (17.5-8), otherwise conflicts with slow start-up NPPs could emerge and lead to short-term surplus in production and large electricity export at low trading prices (Wirth, 2018: 36). On the other hand limiting electricity feed in by SPPs would lead to losses of revenues that is also not recommended. All these market and technical constrains could decrease the level of possible electricity generation in peak load for utility scale PV in 2035.

Considering maximum level of electricity generation in peak load, performance PV ratio of < 85%, and absence of storage systems in Ukraine, recommended possible solar PV installed capacities in 2035 could be amounted to 11 176 MW (11 176 = 9.5 million kWh/85%PR ratio/1000) with yearly power production of 13 412 million kWh, although even this level could be lower considering further deployment of wind power generation, as well as TPPs with 25 500 MW capacities that can't be shut-down for the reason of providing intermediate load when solar power is inaccessible.

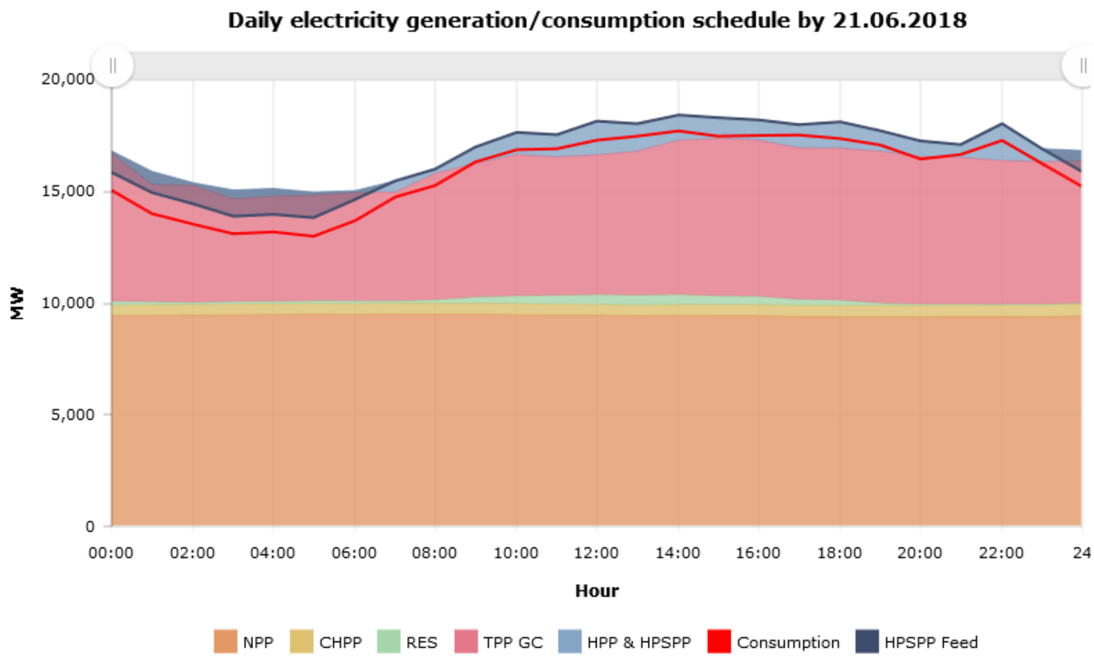


Fig. 6.1: Daily Ukrainian electricity generation/consumption schedule on June 21, 2018
Source: Ukrenergo (2018b)

Above mentioned data show that electricity system of Ukraine with high nuclear power base-load supply could restrain REN deployment, thus base-load demand is not recommended in such amount and nuclear power is not a reliable base-load supplier that often produce power when system do not need it and can't produce more when consumption is increasing. Thus "*electricity system really needs flexible power and flexible demand so that supply and demand can be matched instant by instant. (…) All nuclear power stations are subject to tripping out for safety reasons or technical faults*" (Diesendorf, 2016b) or for prolongation maintenance. That means that electricity system of Ukraine that includes 13 835 MW nuclear power capacities needs at least 4 000 MW of expensive reserve what is shown by average total capacity utilization factor of 71.3%.

Thus for the purpose of minimisation of the influence of the market and technical barriers on utility scale PV deployment till 2035 in Ukraine that could possibly restrain its development by 11 176 MW of installed power capacities, it is recommended to phase out more than just 2 635 MW nuclear power capacities or install additional high flexible capacities such storage systems accept existing PSHPP that is used by NPPs in the night time.

Economic barriers

As it was shown above technical and market barriers limit the deployment of utility SPP to 11 176 MW installed power capacities that could produce in peak load period 9.5 million kWh and yearly – 13 412 million kWh but economic factors such as investment climate and financial support policy influence such deployment even more. It is shown in previous paragraph 2.3 solar PV deployment shows increase in development by 100% for the last 3 years and in 2018 400 MW of power capacities could be installed as first 6 months of 2018 showed 205 MW installed power. 2018 could be the most intensive year of solar PV development from the 2011 when current PV incentive policy was introduced. If this economic trend could be preserved it is possible to install additionally 7 200 MW capacities from 2018 till the end of 2035 (7 200 = 400*18) to the existed 742 MW in 2017 (see table 2.4). The assessment of solar PV power generation is presented in chapter 9.

It should be noted that all SPP projects in Ukraine are financing by privet investor that reasonably want to reimburse his investments and have reasonable rate of income. All incomes from SPP projects are provided by FIT and the level and duration of FIT could stimulate or absolutely stop such solar PV deployment as FIT and electricity prices have not reached grid parity yet as shown at chart 6.1.

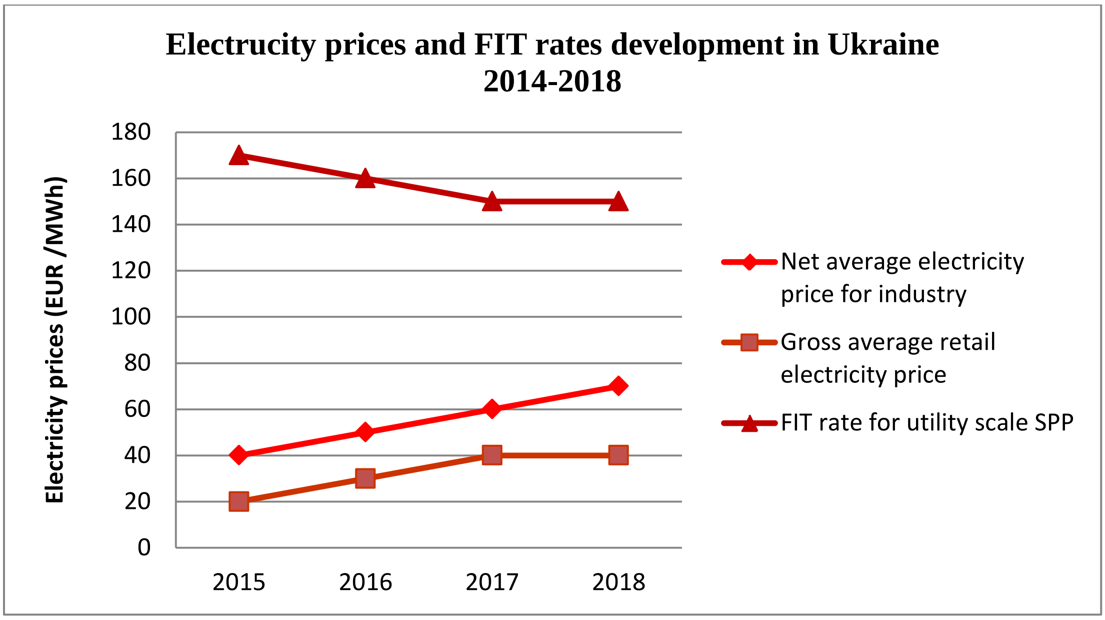


Chart 6.1: Electricity prices and FIT rates development in Ukraine 2014-2018
Source: NERC (2018 d, e)

It would be shown more precisely in paragraph 7.3 that from 2020 the FIT rate will be reduced from EUR 150 to 135 per MWh for new build SPP and duration of FIT is limited by 2030. This restriction of FIT period will lead to increase of WACC and influence LCOE dramatically as investors can't appreciate risk of low electricity purchase price after 2029. Thus LCOE could exceed FIT rate and in such way from 2020 set aside the deployment of solar PV project for the time when electricity market prices will meet LCOE and at least currency risks will be preserved.

6.2 Conclusions

Summarising abovementioned it should be noted that electricity generation in peak load period in summer days (17.5 million kWh on June 21, 2018), lack of storage systems (1500 MW PSHPP), huge nuclear power daily base load (up to 10 million kWh) with high possibility could constrain additional solar PV deployment by 2035 with 7 200 MW power capacities, but outdated PV incentive policy could restrict even such development after 2020 for uncertain time. In chapter 7 current approaches of PV incentive policy and Ukrainian incentive policy are discussed to make further due assessment of current PV support policy.

Chapter 7: Current approaches of solar PV support policies. Ukrainian solar PV support policy

In this chapter it is proposed to make short introduction to current approaches for solar PV policy and Ukrainian legislation on this issue with a view to discuss how the current PV incentive policy could restrict nuclear power replacement with utility scale SPP associated with not appropriate financial support for SPP after 2020 and what policy instruments need alternation.

7.1 Current approaches for solar PV incentive policy

General overview of incentive polices that could be applied for PV development is presented in this chapter.

Despite the fact that the cost of solar PV has come down dramatically and continues to fall for utility-scale SPPs deployment direct or indirect financial support are still required in order to attract sufficient investment in new projects (IFC, 2015:135).

It should be noted that additional financial support is defined by targets that each country envisage for its future electricity market. The success of the implementation of such support depends on electricity demand and peoples approval of REN sources. All instruments of such financial support as well as other measures make up incentive policy of the state.

REN national targets for solar power generation could be reached also by increasing of electricity prices as no incentives needed when price parity is reached. For instance, retail prices in Germany reach EUR 280/MWh that is resulted in PV installation mostly by households' then utility scale SPPs.

If electricity purchase prices are low, SPP developer really needs a guaranty of a fixed price level during investment horizon of SPP otherwise; the construction of new SPP could be postponed as current trends show that SPP investment costs continue to decline. One more factor in favour of fixed price is that "*since all the installed SPP produce electricity at the same time, the more expensive electricity from the older power plants becomes no longer competitive with time, if no price guarantee is in place.*" (Wirth, 2017: 8). Thus FIT in different interpretations remains the most common price-driven instrument to attract investment for SPP deployment. FIT could give necessary guaranty to investor as to his income but this instrument hardly control the installed quantity of SPPs in certain period of time

(Wirth, 2017: 9). *"To delay PV expansion in hopes of lower costs in the future would not only be a cynical reaction with respect to the progressing climate change but would also slow down the dynamics of cost reductions."* (Wirth, 2017: 9).

Thus some countries use quantity-driven instruments that envisage binding quotas that require market players buy a specific percentage of power from a REN source. Using such instrument SPPs developers have guaranty to supply electricity generated by SPPs.

Both above mentioned price-driven and quantity-driven instruments could be implemented and supplemented with other financial support measures such as direct or indirect tax reductions and credits, direct public support schemes, such as soft loans. *"Policies that guarantee and facilitate connection and access of PV plants to the grid are also important for the viability of PV projects by removing common barriers"* (IFC, 2015:135).

For choosing and what is more important evaluating support instruments for PV deployment policy makers should take into consideration different financials numbers and the most important is LCOE for a SPP that is the ratio between the total costs of the plant, operating costs over a lifetime of SPP and its total discounted electricity production value over its economic lifetime.

The lower the LCOE the less support resources are needed for PV deployment. Thus below mentioned instruments are mainly directed to minimize LCOE to the investment attractive level and at the same time not imposing much burden on electricity consumers:

• FIT. FIT is guaranteed by state or local authority purchase price for every kWh of electricity generated by a SPP and paid under a long-term power purchase agreement (PPA). As usual new build utility-scale SPP has to receive approval from public authorities to obtain the FIT. The FIT rates within one state can vary during the lifetime of SPP and/or depend on installed capacity or geographic location of SPP (IFC 2015: 136);

• Reverse Auctions and Tenders. Reverse auctions for solar PV electricity producers envisage competitive determination of guaranty fixed purchase price for electricity generated by SPP or amount of premium to market price. Reverse auctions could specify site or region where a new SPP capacities must be built. Reverse auctions can be neutral to the renewable source of power production where different REN projects compete with each other or restrict competition only among solar PV projects. If a site preselected by public authorities and usually some preparatory work is done like land documentation or/and grid connection, a specified state body will conduct a tender to determine the developer of the site (IFC, 2015:136).

• Quota obligations. Quota obligation instrument imposes obligation to produce, sell and/or purchase specific amount of electricity generated by renewables (quotas) on legally defined members of state electricity system such as power producers or distribution/transmission system operators. Such quotas are legally binding and could bring financial responsibility for non-fulfilment. The power prices could be defined by mutual agreement or at FIT rates determined by legislature. (Wirth, 2017: 10). "*Yet another model for quotas is one that allows for the renewable energy to be "stripped" from the electricity itself and be traded in the form of renewable energy credits (RECs), also called green certificates. RECs are so called "proofs" of purchasing of specific amount of electricity generated from REN sources."* (Wirth, 2017: 10).

• Tax incentives. Tax exemptions could be given to SPP projects with the aim to reduce LCOE by offsetting capital costs or future profits. Capital costs and value of capital could be reduced by partially or fully cancelling import VAT and duties for PV equipment and future profits could be increased by income tax exemptions or accelerated depreciation.

• Soft Loan. Soft loans mean loans with a below-market interest rate or other favourable financial conditions that is typically granted by state financial institutions.

All those mechanisms are specially intended to provide deployment of PV technology by privet equity against conventional power supply options and especially nuclear power that in many countries financing directly by public funds (IFC, 2015: 146).

The above mentioned direct and indirect support monetary instruments are designated to attract privet investments in REN sources deployment against fossil fuel electricity generation sources and in respect with state targets incentive polices and instrument vary widely between regions of the world and states.

7.2 Solar PV incentive policy in Germany

The most vivid and long-running example of practical use of PV incentive policy in Germany is given below.

First of all it should be noted once more that Germany is one of the EU states that took decision phase out its nuclear power capacities till 2022 be replacing them mainly by REN sources. Thus Germany nuclear phase out targets require huge deployment of solar capacity. "*The EEG 2017 specifies a fixed expansion corridor for PV as a share of gross electricity consumption, attempting to both support and restrict the growth in PV capacity.*" (Wirth, 2017: 10).

• For SPP above a certain nominal power (ca. 0.1 MW), self-consumed PV power is subjected to an EEG levy;

• New SPP up to 0.1 MW could receive fixed feed-in tariff;

• New SPP between 0.1 and 0.75 MW obliged to sell power directly on the electricity market;

• New SPPs over 0.75 MW are subject to auctions and power generated by such SPPs may not be used for self-consumption.

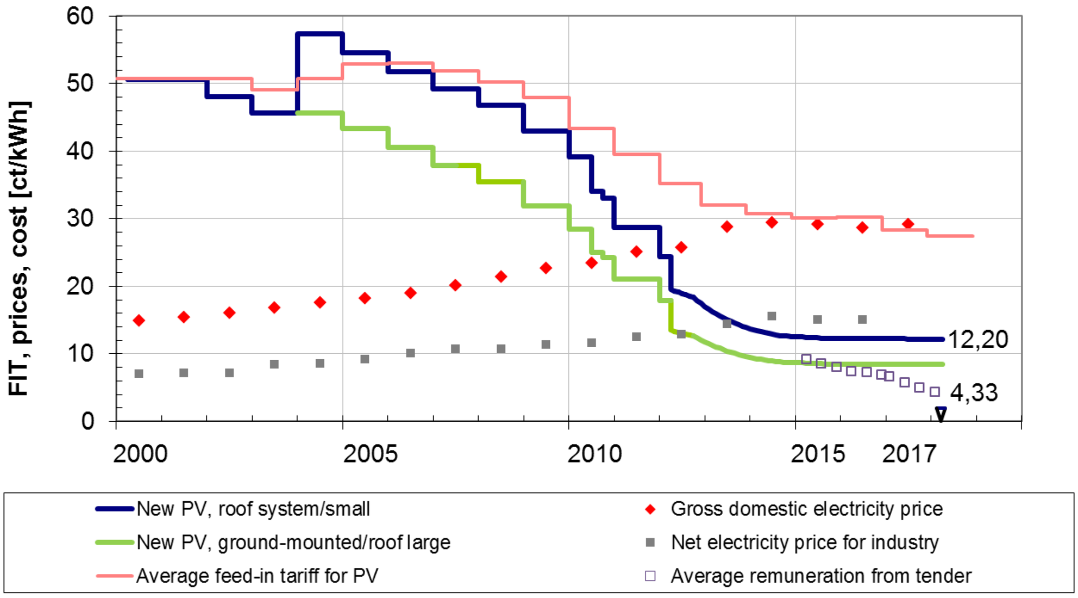


Fig. 7.1: FIT, prices, costs development in Germany
Source: (Wirth, 2017: 10)

As could be seen from figure 7.1 the FIT rate for new roof mounted SPPs commenced by April 2018 amounted to EUR 120 /MWh and is fixed for the next 20 years. For SPP from 0.75 MW up to 10 MW, the FIT is set through auction procedure by the licensing agreement and on February 1, 2018 set a value of EUR 43/MWh. Figure 7.1 also shows that FIT for SPP is decreasing and in 2011 new build utility-scale SPP already achieved grid parity. On July 1, 2013 the remuneration for the electricity generated from new build SPP reached grid parity closely matching the estimated costs for nuclear power production (Wirth, 2017: 11).

EEG envisages that the total costs for the remuneration of solar PV FIT are determined each year by the TSO and in 2017 amounted to EUR 10.35 billion.

The remuneration of FIT will gradually expire for the oldest SPPs after 2020, as their 20-year payment period is reached. "*However, these plants will continue to supply power at levelized costs*…" (Wirth, 2017: 11).

In Germany the gap between the remunerations and the costs of the power generated by SPP electricity is covered by the EEG surcharge. In 2018 the EEG surcharge imposed on private households amounted to EUR 80/MWh including value added tax (19%) (Wirth, 2017: 16).

However energy-intensive industries like chemical producers are excluded from the EEG surcharge to a large extent. In 2015 industries were relieved of costs totalling EUR 4.8 billion and this exemption increases the burden on the other electricity customers, in particular, private households (Wirth, 2017: 15).

Thus Germany demonstrate the incentive policy that envisage 20 FIT period, different approaches that depend on capacity size of solar PV system and what is more important the clear source for financing of the support policy is defined by imposing surcharge for most of the electricity consumers.

7.3 Solar PV support policy in Ukraine

Generation of electricity from RES in Ukraine nowadays is financially supported through a feed-in tariff (the so-called "green tariff") that applies to all REN sources.

The implementation of FIT started in January 2009, when basic FIT rates were established by the National Electricity Regulatory Commission (NERC), which were calculated on the basis of electricity prices for retail consumers (NERC Decree No. 251).

To avoid currency devaluation, the basic FIT rate was set at EUR 53.8/MWh and is subject to multiplication by a technology specific co-efficient.

Thus the FIT has two components: the basic tariff – EUR 53.8/MWh and the technology or source coefficient Green tariff = basic tariff x green coefficient (article 17-1 of the Law on Electricity).

Early from April 2013 till July 2015 it was also additional coefficient 1.8 peak hours for ground mounted SPPs that is not valid from July 15, 2015 for ground mounted SPPs > 10 MW power.

Under the law on Electricity, wholesale electricity market that is state owned company Energorunok is obliged to buy the electricity generated by SPPs at FIT rates.

The FIT rates are set only by the Parliament of Ukraine by passing a Law while other tariffs inter alia for producers of electricity using fossil fuels are set by NERC.

Table 7.1 and chart 7.1 show the development of the FIT rates for ground mounted SPPs and there changes from April 2013 till now. Table 7.1 shows that in July 2015 Ukrainian Parliament decreased the FIT rate for ground mounted SPPs with installed capacity more than 10 MW power. The reason for such retroactive measures was strictly political motivation as most of the SPPs that were affected by such decision belonged to one owner.

For installations commissioned between 1 July 2015 and 31 December 2024 using equipment that produced in Ukraine there is an additional premium to the FIT. For SPPs using at least 30% of such equipment the premium is 5% of the tariff and for installations using at least 50% of such equipment – 10%.

Table 7.1: FIT rates for new commenced ground mounted SPPs in Ukraine

<table>
<tr><th>Source</th><th colspan="8">FIT rates for new installed ground mounted SPP in EUR / MWh</th></tr>
<tr><td colspan="9">Valid from April 1, 2013 till July 16, 2015</td></tr>
<tr><td></td><td>Till 31/03/13</td><td>01/04/13-31/12/14</td><td colspan="4">01/01/15-31/12/19</td><td>01/01/20-31/12/24</td><td>01/01/25-31/12/29</td></tr>
<tr><td>SPPs < 10 MW</td><td>465</td><td>339</td><td colspan="4">305</td><td>271</td><td>237</td></tr>
<tr><td>SPPs > 10 MW</td><td>465</td><td>339</td><td colspan="4">305</td><td>271</td><td>237</td></tr>
<tr><td colspan="9">Valid from July 17, 2015 till now</td></tr>
<tr><td></td><td>Till 31/03/13</td><td>01/04/13-31/12/14</td><td>01/01/15-30/06/15</td><td>01/07/15-31/12/15</td><td>01/01/16-31/12/16</td><td>01/01/17-31/12/19</td><td>01/01/20-31/12/24</td><td>01/01/25-31/12/29</td></tr>
<tr><td>SPPs < 10 MW</td><td>465</td><td>339</td><td>305</td><td>169</td><td>159</td><td>150</td><td>135</td><td>120</td></tr>
<tr><td>SPPs > 10MW</td><td>258</td><td>188</td><td colspan="2">169</td><td>159</td><td>150</td><td>135</td><td>120</td></tr>
</table>

Sources: The Law of Ukraine "On Electricity", The Law of Ukraine "On Electricity Market", The Law of Ukraine "On Alternative Energy Sources"

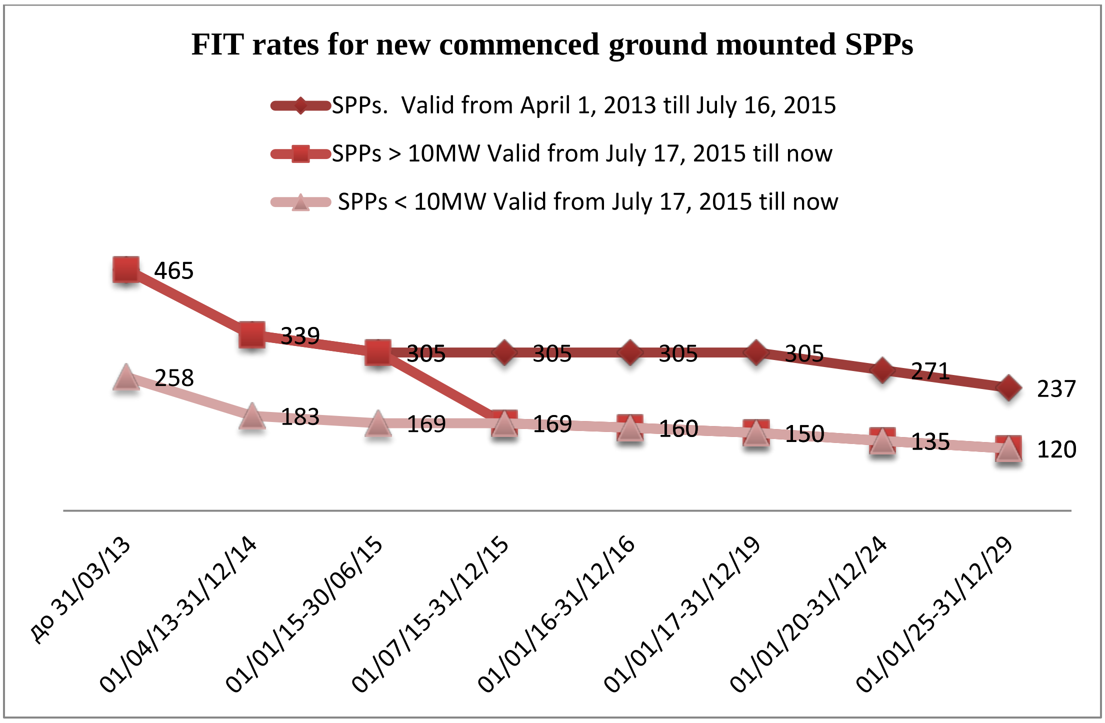


Chart 7.1: Development of FIT rates for new commenced ground mounted SPPs in Ukraine

Sources: The Law of Ukraine "On Electricity", The Law of Ukraine "On Electricity Market", The Law of Ukraine "On Alternative Energy Sources"

NERC is responsible for distributing the financial support to the eligible RES plant operators. The law does not foresee a direct reallocation of these costs to the electricity consumers thus there is now directly defined source for financing FIT in Ukraine.

SPP are contractually entitled to be connected to the grid. Electricity from RES is given priority.

Taking into consideration historical development of PV support policy in Ukraine there are several important conclusions should be considered. Firstly, is that PV generation is very sensitive sphere of investment that need positive political environment as financial support of PV is imposed on consumers although direct relocation of this support is not envisaged. Secondly, it was a precedent of retroactive FIT rates that were mostly influenced rather by political reasons than economic consequences of fast REN development. The cut-off capacity size amounted to 10 MW but this precedent makes investment risks higher and strongly increases WACC. And the third but this time positive issue is that FIT rates are approved by Parliament that guaranty majority policy consensus and are saved from currency risks depreciation as each time recalculated in EURO.

One more important point is that next year some changes in PV incentive policy will occur with start of working of electricity market. More on liberalization of electricity market of Ukraine presented below.

7.4 Electricity market liberalisation in Ukraine

On 13 April 2017 the Parliament of Ukraine adopted Law of Ukraine "On Electricity Market of Ukraine" (The Law on Electricity Market) .The Law on Electricity Market entered into force on June 11, 2017 and should be implemented within two years. The main subjects and instruments of the new electricity market are presented below and shown in Figure 7.2.

- In the new electricity market power producers including NPPs and SPPs shall be allowed to sell electricity at the electricity markets. It is important that new generation capacities shall be constructed under tender procedures. But the Law do not prescribe the size of such new generation capacities (CMS: 2017).
- REN producers shall sell the electricity to the Guaranteed Buyer (state company) under the bilateral contracts at the FIT rates. The Guaranteed Buyer then will re-sell electricity at the day-ahead and intraday markets. The difference between

the FIT and the revenues of Guaranteed Buyer from power sold out at the day-ahead and intraday markets will be reimbursed to the Guaranteed Buyer by the state nuclear power operator NPPs until 2020 and later until 2030 - by The Transmission System Operator (TSO) (CMS: 2017).

- The day-ahead market is based on the auction mechanism where power is selling one day before the delivery date (CMS: 2017).

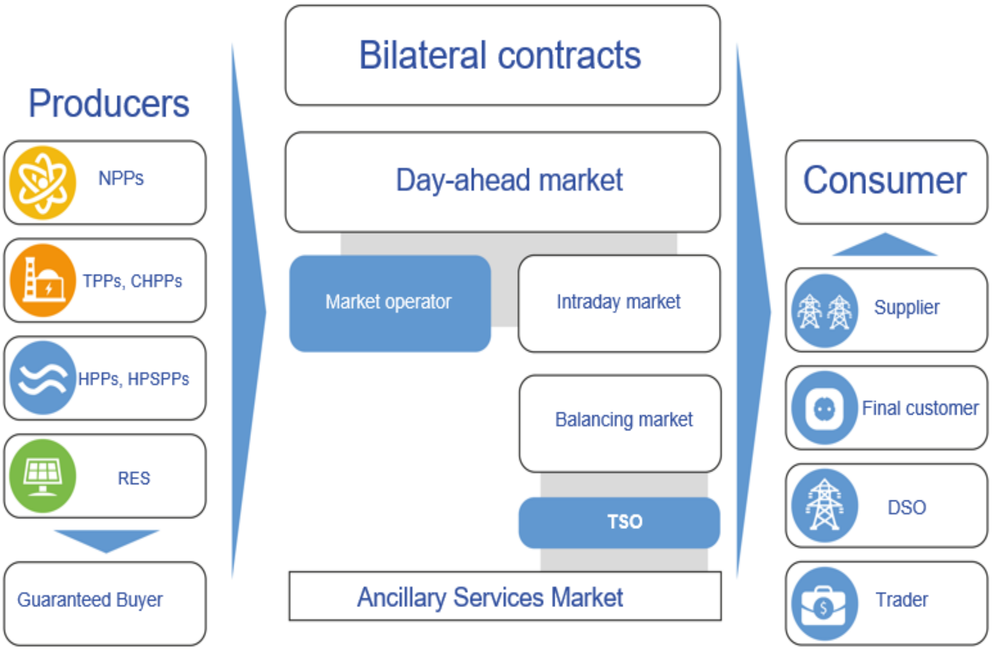


Fig. 7.2: New electricity market scheme
Source: CMS (2017)

- The intraday market envisages real time approach and based on power proposition and demand.
- The SPP should be the member of balancing group that could be solemnly established by state owned company - Guaranteed Buyer as a party responsible for imbalances settlement. The costs of the Guaranteed Buyer associated with the imbalances settlement shall be reimbursed by the REN power producers including SPPs in the shares as stated in Table 7.2.

Table 7.2: Share of imbalanced reimbursement

Period	Share	Period	Share
until 31 December 2020	0	from 1 January 2026	60 %
from 1 January 2021	10 %	from 1 January 2027	70 %
from 1 January 2022	20 %	from 1 January 2028	80 %
from 1 January 2023	30 %	from 1 January 2029	90 %
from 1 January 2024	40 %	from 1 January 2030	100 %
from 1 January 2025	50 %		

Source: The Law on Electricity Market

It should be admitted that all SPPs commenced to the grid before June 11, 2017 are not subject to reimbursement of imbalance till 2030. Also until 2030 SPPs shall reimburse there imbalances only in the case of hourly divergence of their generation to 10% or 5% after reaching by all REN producers 5% of yearly electricity generation in state electricity production balance.

- TSO shall be a 100% state owned company (currently the National JSC “Ukrenergo”) that shall be an owner of the power transmission system and shall administer settlements and perform the functions of the commercial metering administrator at the balancing market (CMS: 2017).
- The power distribution shall be provided by the Distribution System Operators (DSOs) that are not entitled to produce and/or sell electricity. Currently, Ukrainian DSOs also perform supply and generation activity which they will have to unbundle (CMS: 2017).
- The Market Operator is state owned company, which shall manage the day-ahead and intraday markets and provide actual sale of electricity.
- Suppliers shall supply electricity to end consumers at free non-regulated prices (now prices are determined by NERC) (CMS: 2017).

  The market is operated by the TSO, who is responsible for balancing, and who will accept the bids of the market players for load increase or decrease (CMS: 2017).

Thus it should be admitted that new liberalized electricity market that is expected to be launched on July 1, 2019 will not dramatically change the rules for currently existed SPPs. Although, the developers should bear in mind additional costs for new SPP projects associated with balancing of system and electricity production forecast as imbalanced production will be charged.

The Law on Electricity Market made the first but very important step toward interconnections of REN sources and nuclear power that is reimbursement by the NPPs of difference between the FIT and the price of electricity sold by Guaranteed Buyer. Also while TSO will be responsible to reimburse to Guaranty Buyer the difference between electricity market price and FIT rate, the source of such reimbursement by TSO is still not envisaged by the Law on Electricity Market.

7.5 Conclusions

Currently in Ukraine price driven instrument of solar PV support – FIT is implemented. FIT will expire in the end of 2029. As purchase prices of electricity generated by SPP has not reached grid parity and economic situation does not give any ground for such occurrence in the near 15 years, solar PV will still need support for its deployment in Ukraine. In the conditions of electricity market liberalization that is expected to be launched on July 1, 2019, it’s crustal to alternate solar PV support policy with the aim of reaching national REN targets in power generation as well as replacement nuclear power in 2035.

Chapter 8: Assessment of current solar PV incentive policy in Ukraine. Discussion on solar PV policy changes

To assess current solar PV incentive policy in Ukraine the LCOE method was used. LCOE method gives the opportunity to compare costs of electricity generation depending on the year of commencement of SPP from 2018 till 2035 to average solar PV electricity purchase prices that are levelled to FIT rates and current electricity prices for industry. After LCOE calculation and its comparison to electricity purchase prices sensitivity analysis for basic LCOE component - WACC was made. The received results were subject to suggestions for changes of current PV incentive policy in Ukraine.

8.1 Method of approach

As it was shown in paragraph 7.3, under current Ukrainian legislation FIT rate for new installed ground mounted SPPs in Ukraine will decline to EUR 135/MWh from January 2020 and to EUR 120/MWh from 2025 and will last only till 2030.

Thus to assess the possibility of attraction investment in solar PV deployment at least at current level (400 MW/year) after 2020 with a view of replacement nuclear power in 2035, described in paragraph 5.1 LCOE method could be used herein. After calculation of LCOE from 2018 till 2035 it could be compared to average electricity purchase rates generated by SPPs for the same period and showed whether current solar PV support policy is capable to provide further solar PV deployment or needs appropriate changes.

The method of LCOE makes it possible to compare the cost of electricity produced by power plants of different cost structures to electricity purchase prices (grid prices and FIT rates) and thus shows the general long run economic feasibility of PV technology and support policy. The method is a reference point and not suitable for determining the financial feasibility of a specific power plant (Fraunhofer ISE, 2015: 52).

The calculation of the LCOE could be done using net present value method (NPV), in which "*… the expenses for investment and the payment streams from earnings and expenditures during the plant's lifetime are calculated based on discounting from a shared reference date. The cash values of all expenditures are divided by the cash values of power generation.*" (Fraunhofer ISE, 2015: 52).

The LCOE is calculated using the following equation:

(1)

$$LCOE = \frac{Io + \sum_{t=1}^{n} \frac{At}{(1+i)^t}}{\sum_{t=1}^{n} \frac{Mt,el}{(1+i)^t}} = \frac{NPV\ of\ costst}{\sum_{t=1}^{n} \frac{Mt,el}{(1+i)^t}}$$

Io Investment costs (EUR)

At Annual total costs (O&M costs) in EUR in year t

Mt, el Rated production of electricity in the respective year

i Real discount rate in % (WACC)

n Economic operational lifetime in years/investment horizon (Guaranty period of equipment)

t Year of investment horizon (1, 2, ...n)

Source: (Fraunhofer ISE, 2015: 52)

The *Mt, el* is calculated using the following equation:

(2)

$$Mt,el = St(1-d)^t$$

Source: (Branker et al., 2011:5)

"The energy generated in a given year (Mt, el) is the rated energy output per year (St) multiplied by the degradation factor (1- d) which decreases the energy with time. The rated energy output per year can be determined by multiplying the system size/capacity in MW by the local solar insolation that takes capacity factor into account in the units: MWh/MW/yr1." (Branker et al., 2011:6).

"Discounting the generation of electricity seems, at first glance, incomprehensible from a physical point of view but is simply a consequence of mathematic transformations. The idea behind it is that the energy generated implicitly corresponds to the earnings from the sale of this energy. The farther these earnings are displaced in the future, the lower their net present value." (Fraunhofer ISE, 2015: 52).

Thus the main assumptions that should be made in the LCOE calculation are the choice of:

- investment and operating costs;
- discount (WACC) rate;
- PV system investment horizon;
- degradation of energy generation over investment horizon;
- average energy yield at optimal module orientation in Ukraine.

8.2 Comparison of estimated LCOE development to average solar PV electricity purchase prices from 2018 till 2035

To make comparison of estimated LCOE development to electricity purchase prices from 2018 till 2035 the main LCOE assumptions were discussed below.

Investment costs. Firstly, to make LCOE calculation for the period till 2035 proven assumptions of the investment costs should be presented. Investments costs include costs for modules and inverters that make up 51% of total investment costs and remaining costs – costs for balancing of system (BOS) that are mounting systems, installations, cable (DC), infrastructure, transformers, grid connections, planning and documentation (Fraunhofer ISE, 2015: 40). As it was calculated in Fraunhofer ISE study: "Current and Future Cost of Photovoltaics" and shown in chart 8.1 it is envisaged average reduction of solar PV investment costs by EUR 16 000 /MW each year till 2035.

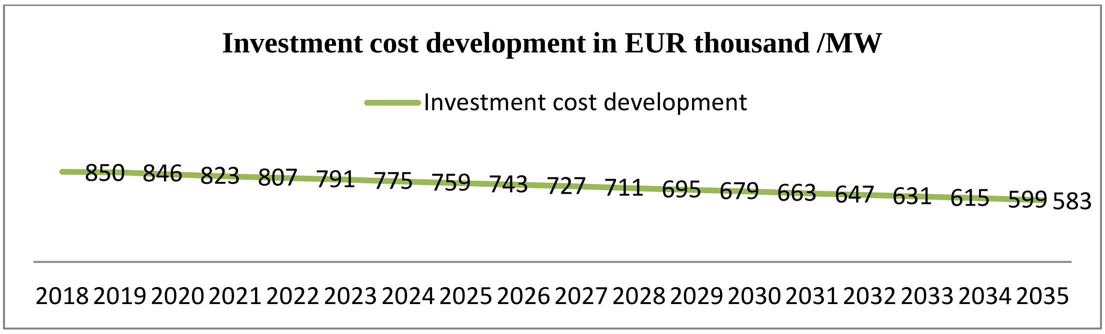


Chart 8.1: Development of investment costs for SPP system (EUR thousand /MW)
Source: own calculations. Data: Fraunhofer ISE (2015).

Chart 8.1 shows the world tendency of reduction of capital costs for solar PV projects. In 2018 turnkey investment costs in Ukraine for 20 MW power SPP amounted to EUR 850 000/MW (Terce, 2018).

OPEX. As it was noted in paragraph 5.3 operating expenditures in 2018 amounted to EUR 5 000/MW that for 20 MW power SPP include: land lease EUR 25 000, wages: EUR 25 000 and maintenance: EUR 50 000. It is often true that the operation and maintenance (O&M) costs rise with the age of the asset (Branker et al., 2011:8). O&M costs per year include the cost of land lease, wages, maintenance costs, administrative expenses. Due to liberalization of electricity market in Ukraine that envisage responsibility for imbalanced production and inflation operating costs could reasonably increase by 5% each year from 2018 till 2035 (Terce, 2018).

Discount rate (WACC). "*A choice of discount rate comes with ample uncertainty and this is dealt with using sensitivity analysis. The concept of discount rate puts a value on time preference on money, which varies by circumstance, location, and the time period considered.(…) The private sector favours higher discount rates to maximize short term profit* (Branker et al., 2011:6).

A proper discount rate should depend on the risk of a project. When all cash flows are certain, for instance when FIT is fixed, a project is risk less and one can value the cash flows by using the interest rates (Kobialka, 2015). If on the other hand the cash flows are not certain, as under current PV incentive policy in Ukraine we don't now the market price for electricity after FIT expiration term (2030), risks are higher and discount rate to be valued in accordance with existent risks. Thus in this paper for calculation of the discount rate the WACC method is chosen. WACC method combines debt and equity costs as well as corporate tax reduction on payable interests and also includes policy risks.

The WACC are calculated using the following equation:

$$WACC = \left(\frac{E}{E+D}\right) Re + \left(\frac{D}{E+D}\right) Rd\ (1 - Tc) \tag{3}$$

E Amount of Equity (EURO)

D Amount of debt (EURO)

Re Cost of equity (%)

Rd Cost of debt (%)

Tc Corporate tax rate (%)

Source: (Kobialka, 2015)

As it was stated in paragraph 5.3, under experts view WACC for utility solar PV projects amounted to 11% in 2018 that assume effective 12% cost of debt that includes risk costs and 8% cost of equity (Terce, 2018).

Investment horizon. Economic life for a SPP system is used to be considering as the manufacturer's guarantee period which in general vary from 20 to 25 years. However the working time of the SPP could be higher and the ability to produce power at economically acceptable level should be considered, since annual O&M costs will rise. After expiration of the economic lifetime, the appropriate decision needs to be taken whether SPP could be replaced or at least retrofitted (Branker et al., 2011:8). It should be noted that the life of many PV power plants is much longer than rated. Thus, the investment horizon of the SPP depends on the estimated acceptable level of power production, which also depends on the degradation factor (amount of power reduction during SPP investment horizon). Average SPP investment horizon is taken in this paper as 20 years taking into consideration the guaranty period in Ukraine from the main equipment suppliers (Terce, 2018).

Solar PV system degradation. Solar panel degradation of about 0.5% per annum correspond to solar panels suppliers warranties (Terce, 2018) and used in financial models. In general, a degradation rate of 0.2%-0.5% per year is considered reasonable given technological advance. (Branker et al., 2011:9).

Electricity yield. The rated power production per year can be calculated by multiplying SPP capacity in MW by the amount of solar insolation at the site considering capacity factor into account in MWh/MW/year. This value could be determined by multiplying the number of days in the year (8760) by average number of hours per year the solar PV system operates by system size to get the final units of MWh/year (Branker et al., 2011:6). As shown in paragraph 5.3 average yearly electricity yield at optimal module orientation in Ukraine: 1200 MWh/MWp (85% percent performance ratio).

All calculations below are presented at the example of SPP with 20 MW installed power capacity.

Summarized set of assumptions for LCOE calculations presented below in table 8.1.

Table 8.1: Key set of assumptions for LCOE calculations

Parameters	Assumptions
Investment cost	EUR 823 000/ MW. EUR 16 000/MW decrease each year.
OPEX	EUR 5 000/MW. 5% increase each year
Discount rate (WACC)	11%
Investment horizon	20 years
Solar PV system degradation	0.5 % each year
Electricity yield	1200 MWh/MWp
SPP rated capacity	20 MW installed power capacity

Source: Terce (2018), Fraunhofer ISE (2015), Branker et al. (2011), NERC (2018c)

Thus when all necessary assumptions are made LCOE development is calculated and its results presented in chart 8.2 and Appendix 3.

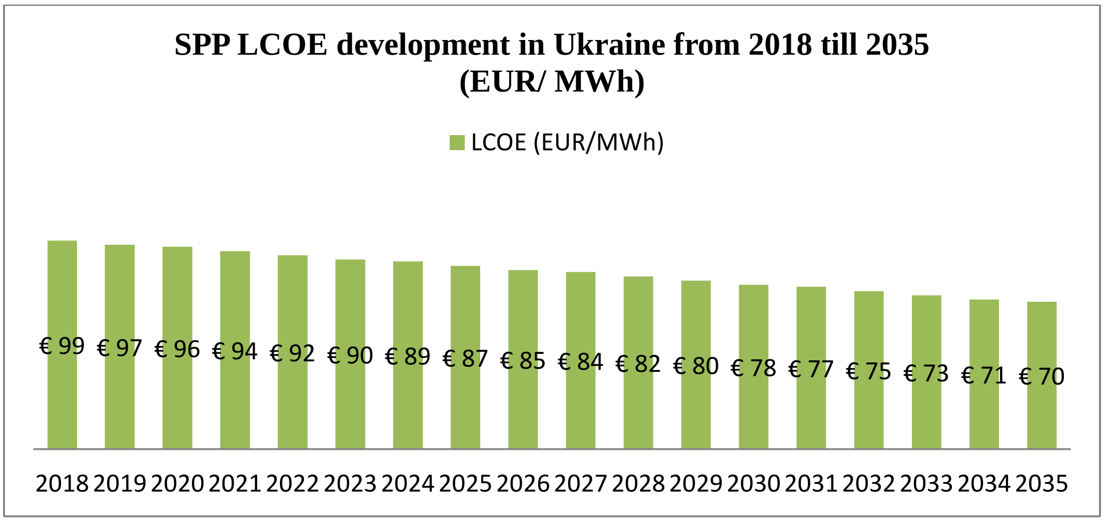


Chart 8.2: SPP LCOE development from 2018 till 2035 in Ukraine (EUR/MWh)
Source: own calculations on the basis of Fraunhofer ISE (2015) data

It should be admitted that chart 8.2 basically shows only the sensitivity of LCOE to the future trends of yearly reduction of investment costs by EUR 16 000 MWh for utility scale SPP system.

As it was noted above LCOE method could be used to assess feasibility of current solar PV policy that is based in Ukraine on FIT tariffs. As LCOE method presents average cost of electricity during SPP investment horizon of 20 years, for comparison reasons the average electricity purchase price that is FIT till 2030 and industry prices from 2030 for the same period should be taken.

As it was shown in paragraph 7.3, FIT rates for new installed SPPs in Ukraine will decline to EUR 135/MWh from January 2020 and from 2025 to EUR 120/MWh and will last only till 2030. After 2030 SPP will sale electricity by nonguaranteed market prices. As it is impossible to predict market prices for electricity in Ukraine after 2030 especially in foreign currency for the aims of this paper it is taken current net average electricity price for industry as shown in the chart 6.1 at EUR 70/MWh. For instance, average electricity purchase price for LCOE comparison in 2018 was calculated:

118 = (current FIT rate in 2018 [EUR135/MWh]*12 + el. price for industry [EUR 70/MWh)*8/20

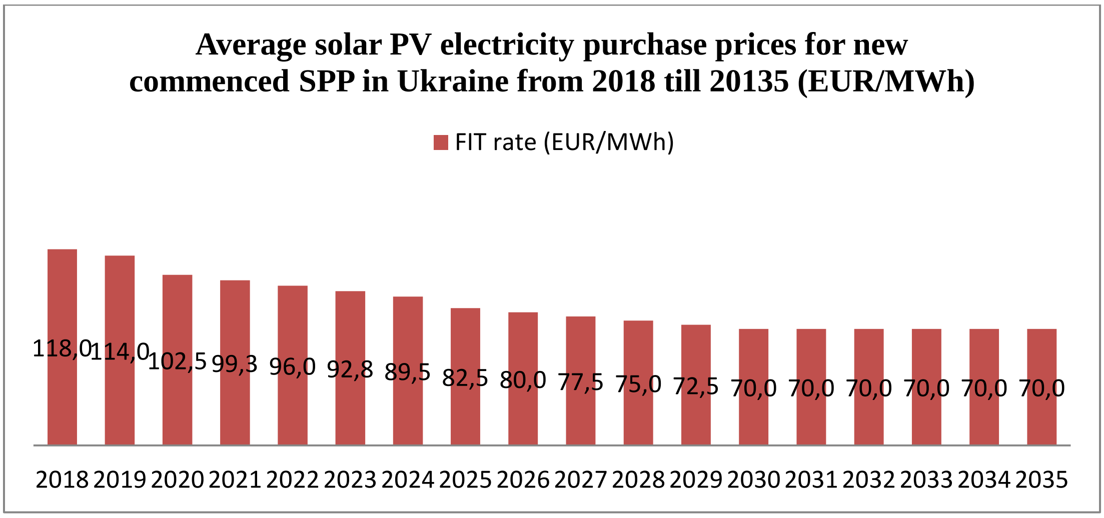


Chart 8.3: Average solar PV electricity purchase prices for new commenced SPP in Ukraine from 2018 till 2035 (EUR/MWh)
Source: own calculations

Chart 8.3 shows average electricity purchase price for utility scale SPP in the year of its commencement into operation and could be compared to LCOE levels from chart 8.2 as LCOE also reflects average value for 20 years.

Thus in the chart 8.4 below the comparison of SPP’s LCOE and estimated electricity purchase prices generated by SPP under current incentive policy are presented and in table 8.2 the ratio of average solar PV electricity purchase prices to LCOE is calculated.

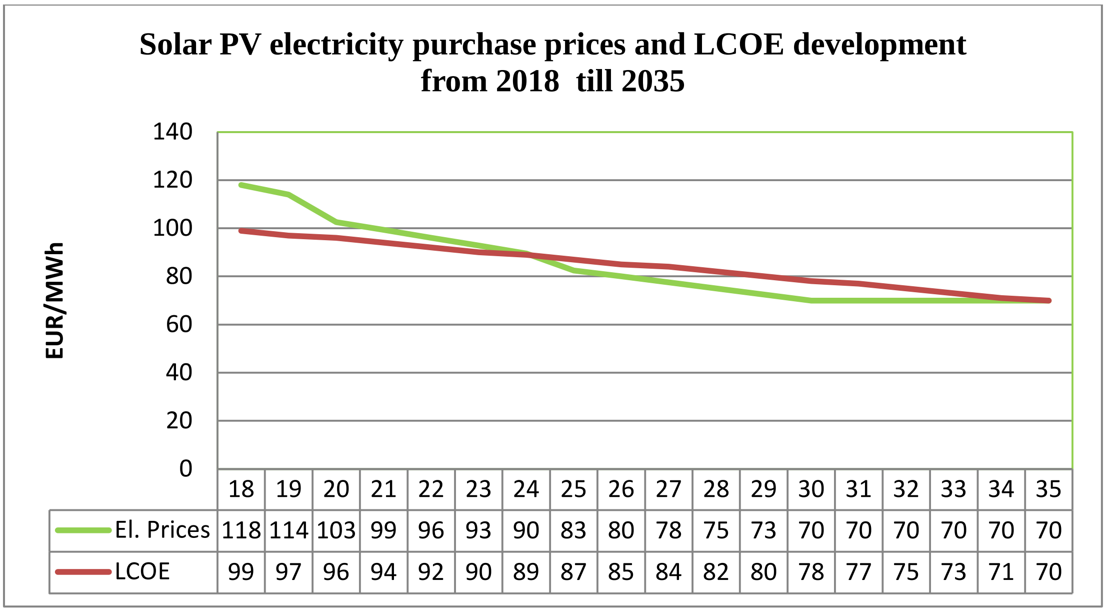


Chart 8.4: Average solar PV electricity purchase prices and LCOE development from 2018 till 2035 under current incentive policy in Ukraine (EUR/MWh)

Source: own calculations

Table 8.2: Ratio of aaverage solar PV electricity purchase prices to LCOE from 2018 till 2035

Year	2018	2019	2020	2021	2022	2023	2024	2025	2026
Ratio of el. price to LCOE	1.19	1.17	1.07	1.05	1.04	1.03	1.01	0.95	0.94
Year	2027	2028	2029	2030	2031	2032	2033	2034	2035
Ratio of el. price to LCOE	0.92	0.91	0.91	0.89	0.90	0.93	0.96	0.98	1

Source: own calculation

Chart 8.4 and table 8.2 clearly show that current (2018) ratio of average solar PV electricity purchase prices and LCOE that is 1.19. Under such correlation the maximum solar PV deployment in Ukraine was reached as also seen from chart 2.3 and could be amounted this year to 400 MW of installed power capacities with 480 million kWh power generation. Thus 1.19 ratio of average solar PV electricity purchase prices to LCOE provide attractive environment for investments in solar PV and serve as a financial index of investment attractiveness (profitability) of solar PV projects.

Table 8.2 also shows that starting from 2020 and till the end of 2024 the profitability of new installed utility scale solar PV projects will decrease and after 2025 LCOE for electricity production will exceed the average solar PV electricity purchase price calculated for 20 years investment horizon. Only in 2035 LCOE could reach grid parity.

These numbers indicate that with deviation of FIT rate to EUR 135 / MWh solar PV development in Ukraine will substantially decrease its investment attractiveness and after 2024 will not be economically feasible. At the same time FIT rate at EUR 150/ MWh is a huge burden for end consumers especially considering the low amount of generated electricity from REN and one of the largest FIT for SPPs in Europe.

That is why it's recommended to change solar PV incentive policy taking into consideration two main targets. Firstly, decrease FIT rates for utility scale SPPs and, secondly, promote the increases of solar PV power production in order to be able to partly replace yearly NPPs generation in the amount of 16 450 million kWh in 2035.

A possible solution for reaching such targets could be adoption of policy instruments that could influence WACC reduction. For this reason sensitivity analysis of LCOE to WACC changes is presented below.

8.3 Sensitivity analysis of LCOE to WACC from 2020 till 2035

To elaborate policy instruments that could help reach above stated targets the sensitivity analysis of LCOE to WACC is presented herein.

"Regulatory or political uncertainty lead to significantly higher risk profiles and increase cost of capital." (Fraunhofer ISE, 2015: 55).

To decrease FIT rates and at the same time save investment attractiveness in solar PV utility business it is recommended to adopt policy instruments that could influence WACC that is strongly associated with investment risks. Risks mitigation could bring additional decrease in WACC for solar PV deployment. The sensitivity analysis that is presented in chart 8.5 and in Appendix 3 confirms that "*cost of capital is very significant for the LCOE of PV systems, and shows that it can be as important as the level of investment cost decrease or level of irradiation."* (Fraunhofer ISE, 2015: 55).

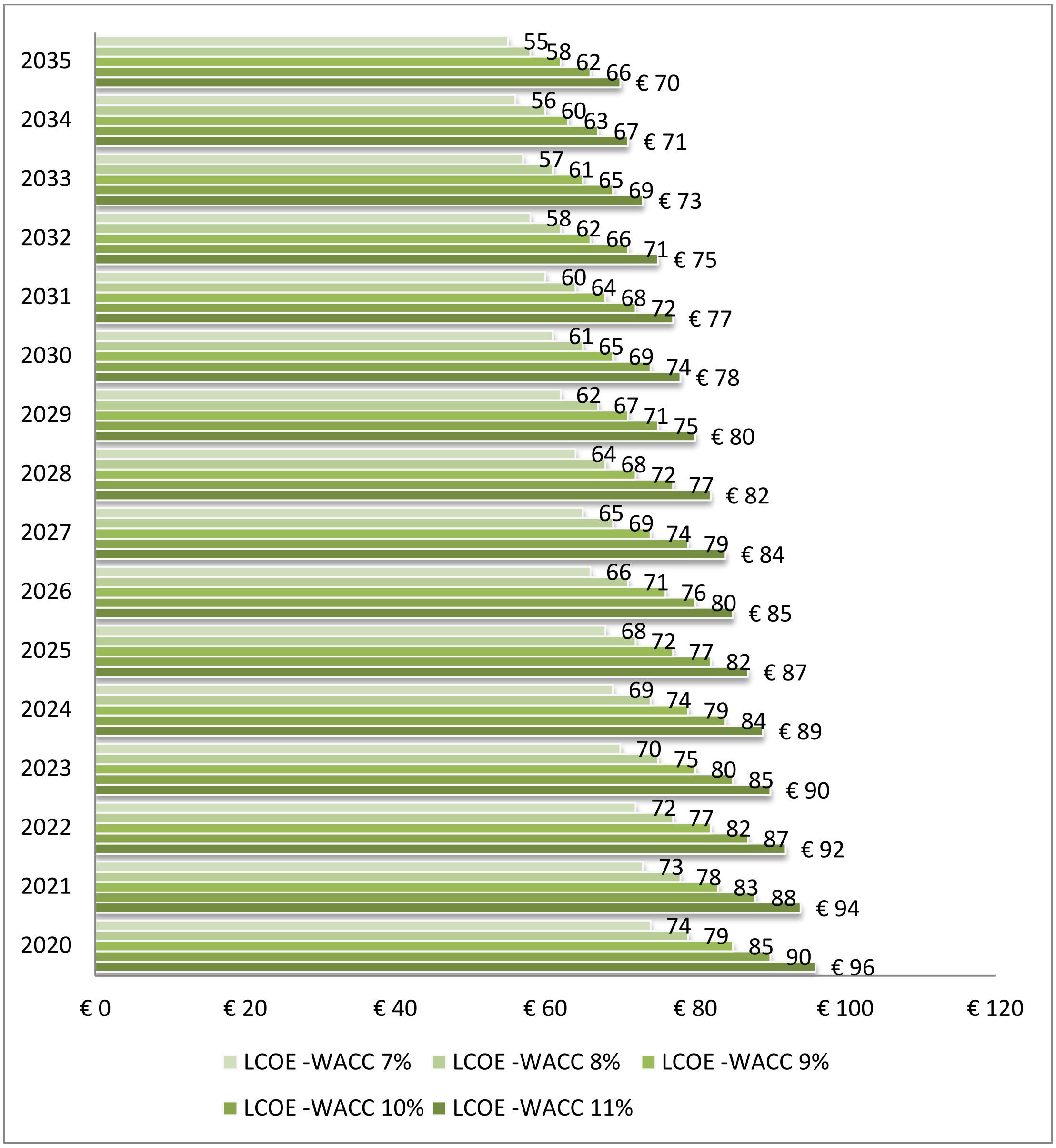


Chart 8.5: Sensitivity analysis of LCOE to WACC decrease in Ukraine till 20135 (EUR/MWh)
Source: own calculation (Appendix 3)

These results clearly show the impact of cost of capital on power generation costs. Thus a new incentive policy instruments could be also focused on investor's risks mitigation that are not under developer's control such as political, regulatory, and permitting risks (permits, feed-in tariff reliability, local content requirement, grid access, etc.); performance risks (electricity off take, bankable PPA) and, financial risk (currency risks, interest and dividends repayment risks).

But there is no methodological approach to assess the influence of specific policy instrument on WACC rate as every country has its own and complex political as well as macroeconomic situation.

8.4 Discussion on solar PV policy changes

As it was shown in chapter 6 electricity generation in peak load, state electricity mix with huge share of nuclear power and current economic trends could constrain the additional PV solar deployment with 7 200 MW power capacity under current state of art of PV technology till 2035. However such development is possible if only current trend of solar PV deployment could be preserved.

But as it was shown in paragraph 7.3 current PV incentive policy that envisages reduction of FIT and no other instruments to reduce LCOE, will certainly restrict even such trend of solar PV development after 2020 for uncertain period of time.

That is why the possible solution to decrease unpopular high FIT for utility scale SPPs and promote the increases of solar PV power generation in order to be able to at least partly replace nuclear power generation in 2035 could be amendment of current PV incentive policy using progressive approaches.

On 7 June 2018, draft law "On Alternations to Laws of Ukraine regarding Provision of Competitive Conditions for Generation of Electricity from Alternative Energy Sources" No. 8449 (the "Draft Law") was registered in Ukrainian Parliament and gave the green light for political discussions of future REN policy in Ukraine. It is expected that it could be approved by the Parliament during the upcoming year.

The main proposals of the Draft Law are stated below.

- Current FIT policy remains only in relation to ground SPP below 10 MW but with lower rates (from 2020 till the end of 2024 – EUR 105 / MWh and from 2025 till the end of 2029 – EUR 98 MWh.
- Apply REN auctions after July 2019 for new SPP exceeding 10 MW. Auctions envisage reimbursement the difference between the price of electricity on the market and the price fixed in the course of the auction for the period of 20 years. But frameworks for bit prices are not envisaged.
- Yearly PV quota for free capacity approved by the government.

In the support documents to draft law stated that the aim of changes to REN legislation is that FIT in EU lower than in Ukraine and that in 2017 92% of REN investments in the world were directed to wind and solar power. Thus all those suggestions deal nothing with state targets in REN deployment under the Strategy 2035 and do not recognize current financial situation in Ukraine. The target of the REN policy can't be "*to set FIT at EU states levels*".

At the same time such approach to solar PV development hardly could be supported by investors as it is clearly could be seen from chart 8.4 that projects below 10 MW will not be economically feasible with EUR 105/MWh FIT rate that is even lower than current legislation provided and with its duration till 2030.

Under such proposals only few low capacity utility scale SPP will go into operation after 2020. Such arguments are proved by the eight alternative draft laws that were registered in Parliament on the same topic but lobby more business interests then policy visions or targets.

Thus the proposed changes to PV incentive legislation unlikely contribute to nuclear power replacement with cost-competitive SPPs in the amount of additional 7 200 MW till 2035 but only in a short time period save consumers money on electricity bills as much higher investments are needed to build new NPPs starting from 2020.

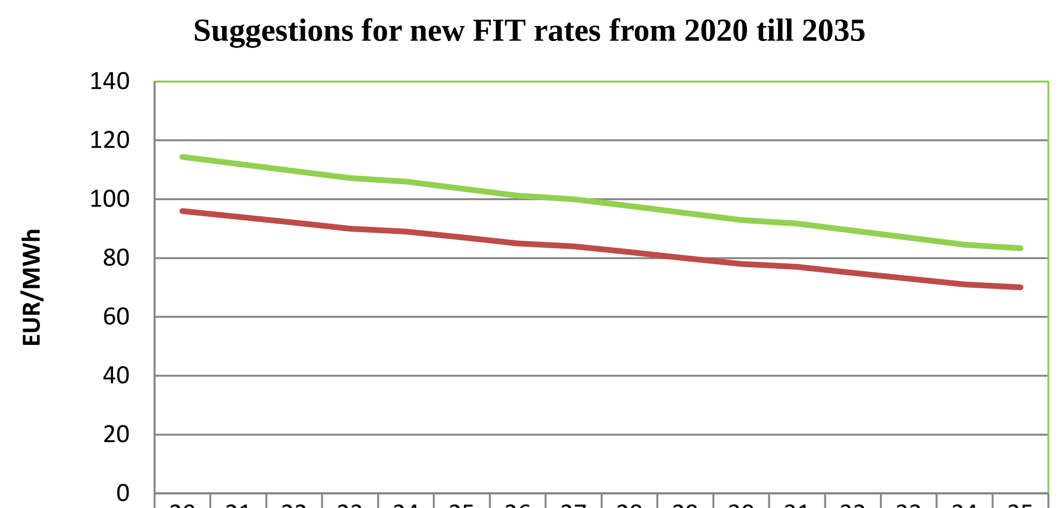
The possible solution to remove barriers to nuclear power replacement with solar PV that associated with incentive policy in Ukraine is to amend economically feasible instruments to PV support policy that could help in fossil fuel replacement and not impose intensive burden to end consumers.

The reasonable target of new incentive policy could be as stated in draft law the decrease of FIT for solar PV, but at the same time it is recommended that this policy keep investments in solar PV sector at attractive level.

"If countries wish to enhance the deployment of solar PV technology, support levels should be aligned with generation costs, based on realistic assumptions for investment cost and cost of capital in case of price-based support schemes such as FIT systems." (Ragwitz et al., 2012, cited by Resch et. al, 2014:122).

It was noted before that solar PV projects still need financial assistance in Ukraine while retail and industry prices are low.

One of the possibilities to decrease FIT rate and at the same time secure current economic trend of solar PV deployment in Ukraine is merely save the average solar PV electricity purchase prices and LCOE ratio at the level of 1.19 as shown in table 8.2 by introducing yearly stepped down approach to FIT rate in relation to the envisages decrease of investment costs by average EUR 16 000 /MW. For instance FIT rate in 2020 would be: LCOE in 2020 (see chart 8.2) [96]*1.19= EUR114/MWh. Taking into consideration data from charts 8.2 and table 8.2 the suggestion for new FIT rates introduction with their 20 years duration period is given in chart 8.6.



	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
FIT	114	112	110	107	106	104	101	100	98	95	93	92	89	87	85	83
LCOE	96	94	92	90	89	87	85	84	82	80	78	77	75	73	71	70

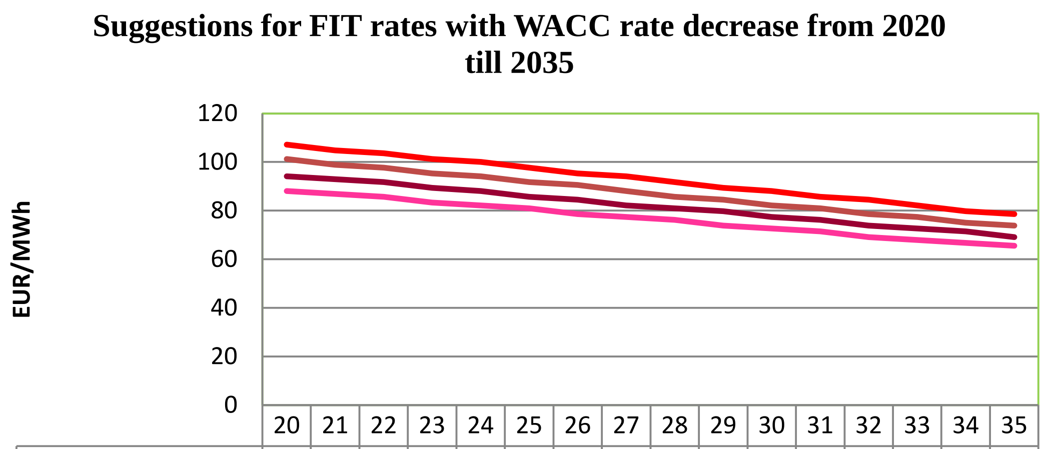
Chart 8.6: Suggestion for new FIT rates in Ukraine from 2020 till 2035 (EUR/MWh)
Source: own calculations

Chart 8.6 clearly shows that such incentive policy instrument as prolongation of FIT duration period to 20 years could significantly allow to decrease FIT rate in 2020 from legislatively envisaged EUR 135/MWh to EUR 114 MWh and in 2025 from EUR 120 MWh to EUR 104/MWh.

As it was shown at chart 8.5 LCOE is very sensitive to WACC rates and decrease of WACC could also significantly decrease LCOE and thus FIT rates.

Chart 8.7 below shows the level of FIT rate that is possible to reach by decreasing WACC by 1% and preserving current ratio of average solar PV electricity purchase prices and LCOE at the level of 1.19.

Also taking into consideration that cost of capital is very significant for the LCOE of PV systems, while implying policy instruments that could mitigate investor's risks and decrease the WACC level, it is recommended to adopt reverse auction in Ukraine for large utility scale SPP above 10 MW installed power and fixed FIT rates as shown at chart 8.6 for utility PV system below 10 MW installed power.



	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
FIT (WACC 10%)	107	105	104	101	100	98	95	94	92	89	88	86	85	82	80	79
FIT (WACC 9%)	101	99	98	95	94	92	91	88	86	85	82	81	79	77	75	74
FIT (WACC 8%)	94	93	92	89	88	86	85	82	81	80	77	76	74	73	71	69
FIT (WACC 7%)	88	87	86	83	82	81	79	77	76	74	73	71	69	68	67	66

Chart 8.7: Suggestion for new FIT rates in Ukraine from 2020 till 2035 with WACC reduction (EUR/MWh)
Source: own calculations

Thus, "*….removal of certain barriers is not only useful to reduce support costs but is also imperative to the realization of new projects.*" (Ragwitz et al., 2012, cited by Resch et. al, 2014:122).

Taking into consideration progressive approaches for solar PV incentive policy that were presented in paragraphs 7.1 and 7.2 the main recommendations of new incentive policy for solar PV that could mitigate uncontrolled investor's risks could be as follows.

Electricity cost decrease driven instruments:

- Set FIT period of 20 years from the date of SPP's commencement.
- Preferential grid access.
- Power purchase agreement (PPA) should have obligatory status for off-taker and obligatory envisage impossible alternation of FIT rate or auction price due to change of legislation. All disputes are to be solved by international arbitration if foreign investments were attracted to the project regardless the amount of such investments.

- Specify that cost for FIT is recovered through specific component of the electricity bill of the consumers. Such measure provides sustainability of the FIT system and in such way lower risks for the inventors.

8.5 Conclusions

It is recommended that new solar PV incentive instruments aiming to provide appropriate financial support level for solar PV deployment and reduction of FIT rates, should be aligned with reduction of investment cost and cost of capital, reduction of generation costs (LCOE), representation of comprehensive world practice, reduction of investor risks, introducing clear source of remuneration (Ragwitz et al., 2012, cited by Resch et. al, 2014:122).

Adoption of costs decrease driven solar PV incentive instruments, save to current attractive average solar PV electricity purchase prices and LCOE ratio at the level of 1.19, could make it possible to decrease the FIT rates to the amounts as given in charts 8.6 and 8.7, pending on FIT duration and WACC level.

It should be also admitted that adoption of new PV policy is not expected till 2020 as it could be subject of political competition in the upcoming Presidential elections in spring 2019 and Parliament elections in autumn 2019.

Chapter 9: Assessment of two possible scenarios

9.1 Assessment of two possible scenarios

In the Strategy 2035 Ukrainian Government made a forecast for power production in Ukraine from wind and solar sources that is amounted in 2035 to 25 000 million kWh. In this chapter the attempt to assess the possible share of utility scale solar PV power production in 2035 under different support policy mechanisms was made.

As it was discussed in chapter 6 the maximum amount of power production in peak load period, state electricity mix with high share of nuclear power and current economic trend that showed 205 MW of installed SPP capacities for the six month of 2018, could currently constrain solar PV deployment in Ukraine to additional 7 200 MW (18 years*400 MW [current trend of 2018]) of installed power capacity from 2018 till 2035.

For the purpose of assessment of additional power production in 2035 by utility scale SPP under current solar PV policy and under suggested in paragraph 8.4 support instruments the possible scenarios for power production by utility scale SPP in 2035 are presented.

Scenario "A" is the reference scenario (continuing as before) when the instruments of the current PV policy remain unchanged.

Scenario "B" is own hypothetical alternative scenario (new policy) that is firstly presented in this paper where reduction of investor risks envisaged. Scenario "B" also includes optimistic, tolerant and pessimistic development.

The key set of assumptions for both scenarios presented in table 9.1 below.

In Scenario "B" 20 years FIT period is proposed. It means that FIT rate set up in the year of SPP commencement would be in force during next 20 years and investor would be secured from marked deviations of electricity prices. As it was shown in chart 8.6, 20 years FIT period could significantly make it possible to decrease FIT rates save to high level of return on investment that is provided by constant ratio of solar PV electricity price (FIT) to LCOE in 2018 at 1.19 point. Also it should be noted that in Scenario "B" that includes optimistic, tolerant and pessimistic development, assumed installed capacity is given in yearly average values for the period of 18 years from 2018 till 2035.

Table 9.1: Key set of assumptions for scenarios for additional solar PV power production in 2035

Parameters	Scenarios			
	Scenario "A" continuing as before	Scenario "B" new policy		
		Optimistic development	Tolerant development	Pessimistic development
FIT duration	till 2030	20 years from the commencement day		
FIT rates	EUR 150/MWh from 2018-2019; EUR 135/MWh from 2020 - 2024; EUR 120/MWh from 2025 - 2029; from 2030 FIT is not applicable, market price in UA currency	EUR 150/MWh from 2018-2019; From 2020 FIT amounted to rates stated in chart 8.6 keeping the ratio of solar PV electricity price (FIT) to LCOE at 1.19		
Assumed installed capacity	950 MW till the end of 2022; from 2023 no further development	400 MW/year (average) from 2018	300 MW/year (average) from 2020	200 MW/year (average) from 2020
Modelling period	2018-2035	2018-2035	2018-2035	2018-2035
Total assumed installed capacity in 2035	950 MW	7 200 MW	5 600 MW	4 000 MW

Source: own assumptions

In Scenario "B" optimistic development envisages installation of average 400 MW of new capacities per year. Value of 400 MW is taken based on current trend of 2018 as the best historical figure of solar PV development in Ukraine. Tolerant and pessimistic development with average yearly 300 and 200 MW installed capacities respectively showed deviation from optimistic development by 75% and 50%. Due to strong decrease in 2020 of solar PV electricity price (FIT) to LCOE ratio under scenario "A" as shown in table 8.2, it is estimated in Scenario "A" that in 2020 only 100 MW of solar PV power capacity would be installed, in 2021 – only 50 MW and starting from 2022 till 2035 the solar PV development would be fully stopped.

During 2018-2019 both scenarios have the same SPP installed capacities assumption – 400 per year.

Modelling period from 2018 till 2035 is taken for the purpose to assess the power production in 2035 by additionally installed SPPs to the base year 2017 and in such way shows the potential of solar PV for nuclear power replacement.

Both scenarios estimate that solar PV technologies remain unchanged up to 2035.

The development of utility scale solar PV capacity under both scenarios from 2018 till 2035 is showed in chart 9.1 and results of such development in 2035 could be found in Table 9.1.

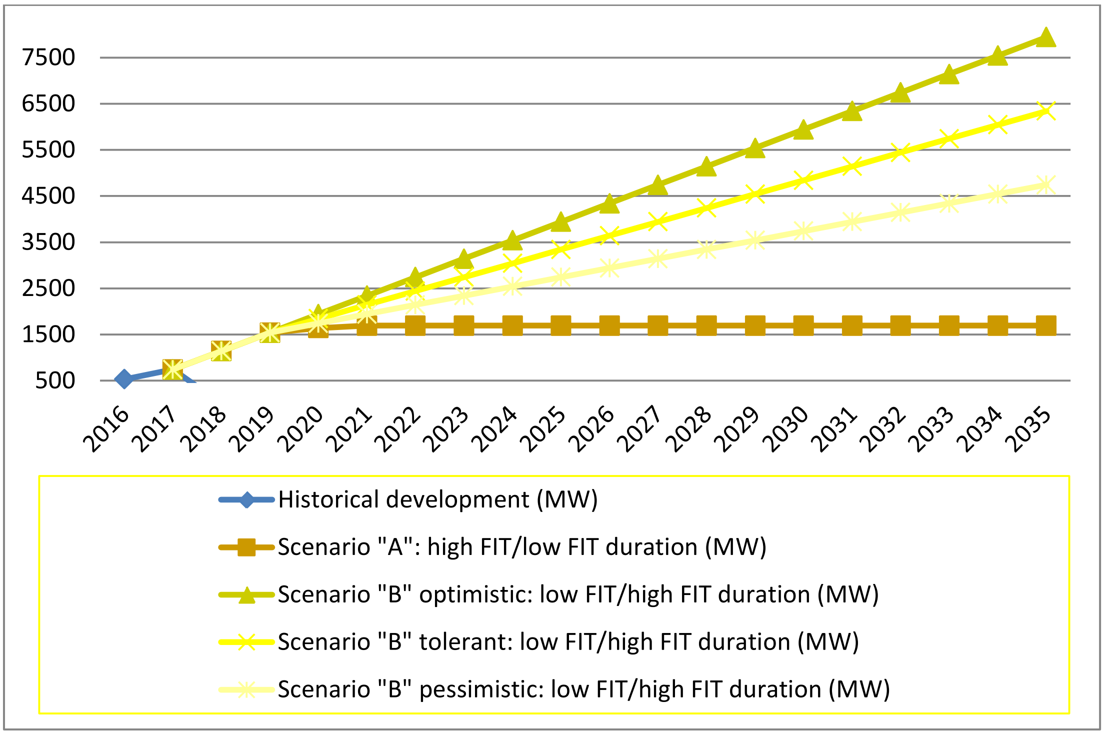


Chart 9.1: Estimated utility scale SPP installed power capacity under scenario "A" and "B" from 2018-2035 (MW)
Source: own chart on the basis of table 9.1

For the estimation of the additional to 2017 solar PV power production in 2035 under both scenarios that is showed in chart 9.2, not only installed capacity utilization factor should be taken into consideration but also life-time of the SPP that is associated with degradation factor of solar panels. Economic life for SPP or investment horizon is usually considered to be the producers guarantee period for main equipment such as solar panels which is often 20 to 25 years. In general, a degradation rate of 0.2%-0.5% per year during PV system lifetime is considered reasonable given technological advance (Branker et al., 2011:9). Thus for the calculation of power production from 2018 till 2035 degradation rate of 0.5% per year is taken.

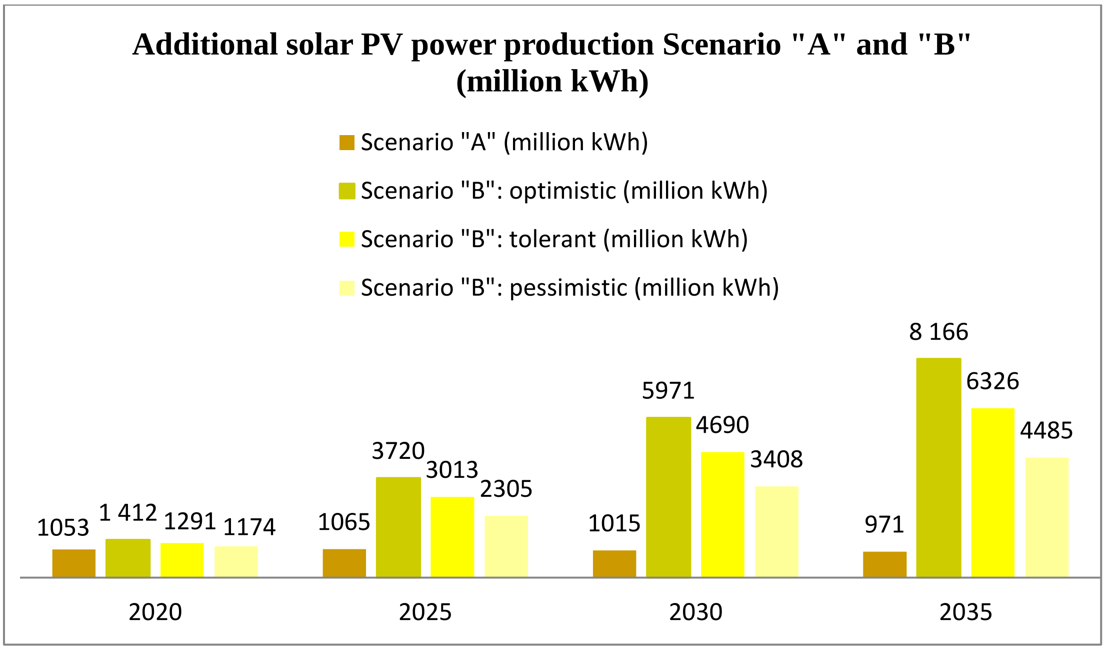


Chart 9.2: Estimated additional to 2017 solar PV power production in 2035 under scenario “A” and “B” (million kWh)
Source: own calculation (Appendix 4)

Also it is considered that as it was shown in chart 2.3 till 2035 400 MW of solar PV installed capacities (during 2031-2035) possibly could expand its guarantee 20 years period and could lose about 10% of their generation potential (but still produce power at levelized costs) unless they are renovated or at least retrofitted. Thus the additional to 2017 solar PV power generation in 2035 should be reduced by the amount of power generation that would not be produced in 2035 (in comparison to 2017) by the SPPs that were installed until 2018 due to their degradation.

Chart 9.2 clearly shows that scenario “B” will greatly strengthen energy independence and improve environmental situation in Ukraine and at the same time sustainable electricity supply. But it should be considered that the level of success of new policy instruments under Scenario “B” is depended on investment risks mitigation, mainly on FIT prolongation to 20 years, and in such way on the cost of capital. Mitigation of other uncontrolled investor’s risks by implementation of measures that are stated in paragraph 8.3 (preferential grid access; direct source of FIT remuneration; possibility to exclude from the jurisdiction of Ukrainian courts dispute resolution under PPA) could make it possible to attract required capital for successful realization of Scenario "B" constantly during next 18 years.

9.2 Conclusions

As a conclusion to the proposed scenarios assessment, table 9.2 shows the amount of possible nuclear power capacities replacement by solar PV in 2035 under scenario "A" and different developments of scenario "B", answering the main question of this paper: "Could utility scale SPPs replace nuclear power capacities that are subject to phase out in Ukraine in 2035?"

Table 9.2: Possible nuclear power capacities replacement by solar PV in 2035

	Scenarios			
	Scenario "A" continuing as before	Scenario "B" new policy		
		Optimistic development	Tolerant development	Pessimistic development
Assumed additional to 2017 SPP power production in 2020 million kWh	1053	12 1412 1291	1174 1291	1174
Assumed additional to 2017 SPP power production in 2025 million kWh	1065	3720	3013	2305
Assumed additional to 2017 SPP power production in 2030 million kWh	1015	5971	4690	3408
Assumed additional to 2017 SPP power production in 2035 million kWh	971	8166	6326	4485
Assumed nuclear power capacities replacement with SPP in 2035 MW	155	1307	1013	718

Source: own table based on chart 9.2 and Appendix 4

Table 9.2 as well as chart 9.2 illustrate that successful (optimistic) realisation of new PV policy under scenario “B” with additional SPP’s power production in 2035 of 8 166 million kWh could meet cost-competitive possibility of the replacement of about 1 307 MW of nuclear power capacities (1307=8166000/8760days*71.3% (total average utilization capacity factor of NPP)). Under scenario “A” solar PV power could replace only 155 MW nuclear power capacities with 971 million kWh in 2035.

Scenario “B” is more preferable but needs solar PV support policy alternation directed at investors risks mitigation and mainly at prolongation if FIT to 20 years.

Chapter 10: Conclusions and recommendations

10.1 Conclusions

1. This research shows that Ukraine is hardly dependent on imported fossil fuels like nuclear fuel and since 2015 coal. The major source of power production plays nuclear power covering more than 55% in electricity mix and providing daily electricity generation base load up to 10 million kWh for electricity system.

2. Great dependency on nuclear power could provoke a great electricity supply disaster as most of the nuclear power capacities are to be phased in 2030th after 50 years of operation: 4835 MW - till the end of 2035. In August 2018 Ukrainian Government restart the process of completion of two NPPs reactors with total installed capacity of 2 200 MW. Thus assuming that if in 2035 electricity consumption in Ukraine will stay at the current level, at least 2635 MW that could generate 16 450 million kWh per year should be replaced with the same or other cost competitive sources. Current Energy strategy of Ukraine till 2035 only declarer awareness of this problem but does not give clear answers how to solve it.

3. At the same time cost of new build NPP in Ukraine could be amounted to EUR 6.5 million/MW that is in prices of 2018 exceeds the cost of utility scale SPP at least by 35% taking into consideration PV local average capacity utilization factor. LCOE for nuclear power production in Ukraine with its average amount of EUR 106 /MWh now could also exceed solar PV generation cost of EUR 99 /MWh and dependent on variety of factors such as capital costs, construction period, plant economic lifetime, value of financing, operational costs and others.

4. Thus solar PV has great cost competitive potential to replace nuclear power in 2035. Under estimation of IRENA made in 2017 a further cost competitive potential for solar PV in Ukraine up to 70 000 MW can be unlocked by 2030 if more stable policy frameworks are provided.

5. However electricity generation in peak load period in summer days (17.5 million kWh on June 21, 2018), lack of storage systems (1500 MW PSHPP), huge nuclear

power daily base load (up to 10 million kWh) and current utility scale solar PV incentive policy (expires in 2030) with high possibility could constrain additional solar PV deployment and thus make it impossible to replace nuclear power by solar PV sources and with lower costs.

6. The renewal of solar PV incentive policy in Ukraine by introducing such instruments as duration of FIT up to 20 years, together with the others power cost capital decrease driven instruments is recommended and could help in investors risks mitigation and reduction of value of financing, and thus make it possible to replace about 8 166 million kWh of nuclear power production in 2035 (approximately 1307 MW NPPs capacity) under optimistic development only with utility scale SPPs and with lower costs than nuclear power really needs.

7. And the last but may be the most important conclusion that is addressed to police makers is that nuclear power with its base load function and low flexibility have big potential to collide with solar PV power and in the near future could constrain REN development in Ukraine.

10.2 Recommendations and discussions

1. Even taking into consideration the positive trend of solar PV deployment in Ukraine and implementation in the near future of new incentive police instruments as well as end of construction of two nuclear power units with installed capacity of 2 200 MW it is obvious that utility scale solar PV power plant with its additional optimistic production potential of 8 166 million kWh in 2035 will not be able to replace remaining power demand caused by 2635 MW phase out nuclear power that produce 16 450 million kWh/year. Thus remaining demand in 2035 of about 8 284 million kWh could be replaced by other REN sources or imported from abroad. It is recommended in further research to assess the challenges and potential of wind power and biomass till the end of 2035 as most promising source of REN in Ukraine as well as storage systems development.

2. This paper is not making assessment of solar PV technology development that could strongly influence the efficiency of PV systems. Further research is needed to assess the possible breakthrough in solar PV effectiveness.

3. Sensitivity analysis of LCOE to WACC showed the great opportunities to decline LCOE and in such way financial support to solar PV deployment in Ukraine. Also more precise research is recommended to assess the drivers of cost of capital in PV systems in Ukraine and especially the impact of policy-making on cost of capital.

4. Even the adoption of recommended incentive policy instruments doesn't mean that investors certainly will come to Ukrainian market to finance solar PV growth at current level. However nuclear power phase out opens great opportunities for commencement of large utility scale SPP using infrastructure of NPPs such as exclusion land zone and grid connection. The example is Germany's Enerparc and Ukrainian firm Rodina Energy group that operating in testing regime 1 MW PV power plant next to reactor of Chernobyl NPP and hope to build in the near future larger SPP with 100 MW installed capacity (PV-tech, 2018). Another example is 246 MW SPP that is under construction of DTEK company near abandoned former quarry that also have necessary BOS structure and thus mitigate investment costs (PV-tech, 2018). And one more reason to invest in solar PV is that PV business is only one opportunity were investors currency risks are secured by state under article 9^1 of Law of Ukraine on Alternative Energy Sources and investment market barriers to start project are very low.

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List of abbreviations

BOS	Costs for balancing of system
CAPEX	Capital expenditures
CHPP	Combined Heat and Power Plant
DSO	Distribution system operator
DSM	Demand side management
EC	European Commission
EU	European Union
FIT	Feed in tariff
GDP	Gross Domestic Product
GHG	Greenhouse gases
GW	Gigawatt
HPP	Hydro Power Plant
ICUF	Installed Capacity Utilization Factor
IEA	International Energy Agency
KhNPP	Khmelnytskyi Nuclear Power Plant
LCOE	Levelized Cost of Electricity
MW	Megawatt
NERC	National energy and utilities regulatory commission of Ukraine
NPP	Nuclear Power Plant
NPV	Net profit value
OPEX	Operating expenditures
PPA	Power purchase agreement
PPP	Purchasing Power Parity
PR	Performance ratio
PSHPP	Pumped Storage Hydropower plant
PV	Photovoltaic
REN	Renewable energy
RES	Renewable energy sources
RNPP	Rivne Nuclear Power Plant
SPP	Solar Power Plant
Strategy 2035	The Energy strategy of Ukraine till 2035
SUNPP	South Ukraine Nuclear Power Plant
SSS UA	State Statistic Service of Ukraine
TPP	Thermal Power Plant
TSO	Transmission System Operator
VAT	Value Added Tax
VVER	Water-Water Energetic Reactor
WACC	Weighted average cost of electricity
WPP	Wind Power Plant
ZNPP	Zaporizhzhia Nuclear Power Plant

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Appendix 1: Nuclear power blocks in Ukraine

NPP Name	Unite No	Installed capacity (MW)	Start of operation	End of the license/ exploitation	Possible term of prolongation
Zaporizhzhia NPP	1	1 000	10/12/1984	23/12/2025	2034
	2	1 000	22/07/1985	19/02/2026	2035
	3	1 000	10/12/1986	05/03/2027	2036
	4	1 000	18/12/1987	04/04/2018	2037
	5	1 000	14/08/1989	27/05/2020	2039
	6	1 000	19/10/1995	21/10/2026	2045
South UKraine NPP	1	1 000	31/12/1982	20/12/2023	2032
	2	1 000	06/01/1985	31/12/2025	2035
	3	1 000	20/09/1989	10/02/2020	2039
Rivne NPP	1	415	22/12/1980	22/12/2030	22/12/2030
	2	420	22/12/1981	22/12/2031	22/12/2031
	3	1 000	21/12/1986	11/12/2037	11/12/2036
	4	1 000	10/10/2004	07/06/2035	2054
Khmelnytskyi NPP	1	1 000	22/12/1987	13/12/2018	2037
	2	1 000	07/08/2004	07/09/2035	2054
	3	1 100	Under construction Estimated start of operation till the end of 2030	-	-
	4	1 100	Under construction Estimated start of operation till	-	-

			the end of 2030		
Chernobyl NPP	1	1 000	27/05/1978	30/11/1996	-
	2	1 000	28/05/1979	11/10/1991	-
	3	1 000	08/06/1982	15/12/2000	-
	4	1 000	26/03/1984	26/04/1986	-

Source: Own table on the basis of the data from UAtom (2018)

Appendix 2: Nuclear power blocks in Belgium

NPP Name	Block No	Installed capacity (MW)	Start of operation	End of the license/exploitation
Doel	1	433	1975	2025
	2	433	1975	2025
	3	1 006	1982	2022
	4	1 033	1985	2025
Tihange	1	962	1975	2025
	2	1 008	1983	2023
	3	1 038	1985	2025

Source: WNA (2018)

Appendix 3: Calculation of sensitivity analysis of LCOE to reduction of investment costs and WACC from 2018 till 2035

Financial Assumptions:

Investment horizon	20	year
WACC (i)	11,0%	year
SPP Rated Capacity	20,0	MW
Energy output per 1 MW/p	1 200,000	MWh
Investment Costs	850 000	€/MW
O&M Costs	5 000	€/MW
Degradation factor of PV modules (d)	0,5%	year
Total Investments Costs	17 000 000	€
Escalation of O&M Costs	5,0%	year
Total rated yearly Electricity generation (S)	24 000	MWh
O&M Costs	100 000	€/yr

Year	**Investment Costs**	**O&M**	**Nominal Costs**	**iscounted Cos**	**El. Generation**	**Discounted El. Generation**
0	€ 17 000 000		€ 17 000 000	€ 17 000 000		
1	€ 0	€ 105 000	€ 105 000	€ 94 595	23 880,000	21 514
2	€ 0	€ 110 250	€ 110 250	€ 89 481	23 760,600	19 285
3	€ 0	€ 115 763	€ 115 763	€ 84 645	23 641,797	17 287
4	€ 0	€ 121 551	€ 121 551	€ 80 069	23 523,588	15 496
5	€ 0	€ 127 628	€ 127 628	€ 75 741	23 405,970	13 890
6	€ 0	€ 134 010	€ 134 010	€ 71 647	23 288,940	12 451
7	€ 0	€ 140 710	€ 140 710	€ 67 774	23 172,496	11 161
8	€ 0	€ 147 746	€ 147 746	€ 64 111	23 056,633	10 005
9	€ 0	€ 155 133	€ 155 133	€ 60 645	22 941,350	8 968
10	€ 0	€ 162 889	€ 162 889	€ 57 367	22 826,643	8 039
11	€ 0	€ 171 034	€ 171 034	€ 54 266	22 712,510	7 206
12	€ 0	€ 179 586	€ 179 586	€ 51 333	22 598,947	6 460
13	€ 0	€ 188 565	€ 188 565	€ 48 558	22 485,953	5 790
14	€ 0	€ 197 993	€ 197 993	€ 45 933	22 373,523	5 191
15	€ 0	€ 207 893	€ 207 893	€ 43 451	22 261,655	4 653
16	€ 0	€ 218 287	€ 218 287	€ 41 102	22 150,347	4 171
17	€ 0	€ 229 202	€ 229 202	€ 38 880	22 039,595	3 739
18	€ 0	€ 240 662	€ 240 662	€ 36 778	21 929,397	3 351
19	€ 0	€ 252 695	€ 252 695	€ 34 790	21 819,750	3 004
20	€ 0	€ 265 330	€ 265 330	€ 32 910	21 710,652	2 693
			NPV of Costs	**€ 18 174 077**	**MWh**	**184 353**

Results:	**LCOE**	**€ 99**	**€/MWh**

$$LCOE = \frac{NPV\ of\ costst}{\sum_{t=1}^{n} \frac{Mt,el}{(1+i)^t}}$$

$$Mt,el = St(1-d)^t$$

Sensitivity Analysis of LCOE to reduction of investment costs and WACC						
Yaer	In.Costs	OE (WACC 11	COE (WACC 10%	COE (WACC 9%	COE (WACC 8%	COE (WACC 7%
2018	€ 850 000	€ 99	€ 93	€ 87	€ 82	€ 76
2019	€ 839 000	€ 97	€ 92	€ 86	€ 81	€ 76
2020	€ 823 000	€ 96	€ 90	€ 85	€ 79	€ 74
2021	€ 807 000	€ 94	€ 88	€ 83	€ 78	€ 73
2022	€ 791 000	€ 92	€ 87	€ 82	€ 77	€ 72
2023	€ 775 000	€ 90	€ 85	€ 80	€ 75	€ 70
2024	€ 759 000	€ 89	€ 84	€ 79	€ 74	€ 69
2025	€ 743 000	€ 87	€ 82	€ 77	€ 72	€ 68
2026	€ 727 000	€ 85	€ 80	€ 76	€ 71	€ 66
2027	€ 711 000	€ 84	€ 79	€ 74	€ 69	€ 65
2028	€ 695 000	€ 82	€ 77	€ 72	€ 68	€ 64
2029	€ 679 000	€ 80	€ 75	€ 71	€ 67	€ 62
2030	€ 663 000	€ 78	€ 74	€ 69	€ 65	€ 61
2031	€ 647 000	€ 77	€ 72	€ 68	€ 64	€ 60
2032	€ 631 000	€ 75	€ 71	€ 66	€ 62	€ 58
2033	€ 615 000	€ 73	€ 69	€ 65	€ 61	€ 57
2034	€ 599 000	€ 71	€ 67	€ 63	€ 60	€ 56
2035	€ 583 000	€ 70	€ 66	€ 62	€ 58	€ 55

Source: own calculations

Appendix 4: Calculation of estimated additional to 2017 solar PV power production in 2020, 2025, 2030, 2035 under scenarios "A" and "B"

Scenarios "A" & "B": additional to 2017 solar PV power production in 2020			
Financial Assumptions:			
	SPPs average yearly installed capacity in MW		**400**
	Average energy output per 1 MW/p MWh		**1200**
	Degradation factor (d)		**0,5%**
	$Mt,el = St(1-d)^t$		
	Total rated yearly Electricity generation MWh (*St*)		**480 000**

Period/y	Electricity generation (Mt, el)	Year
1	477 600	2018
2	475 212	2019
3	472 836	2020

Scenario "B": optimistic	Installed power capacity in y.	Estimated Power production in 2020	Power production reduce in 2020 to 2017
2 011	4	4 565	69
2 012	158	181 237	2746
2 013	171	197 134	2 987
2 014	71	82 262	1 246
2 015	20	23 289	353
2 016	99	115 860	1 755
2 017	211	248 174	3 760
2 018	400	472 836	
2 019	400	475 212	
2 020	400	477 600	
Total		2 278 169	12 916
Additional power production in 2020 to 2017 by capacities installed in 2018-2020		1 425 648	MWh
Additional power production in 2020 to 2017 considering reduction by capacities installed before 2018		**1 412 732**	MWh

Continuation of appendix 4

Scenario "B": tolerant	Installed power capacity in y.	Estimated Power production in 2020	Power production reduce in 2020 to 2017
2 011	4	4 565	69
2 012	158	181 237	2746
2 013	171	197 134	2 987
2 014	71	82 262	1 246
2 015	20	23 289	353
2 016	99	115 860	1 755
2 017	211	248 174	3 760
2 018	400	472 836	
2 019	400	475 212	
2 020	300	356 627	
Total		2 157 196	12 916
Additional power production in 2020 to 2017 by capacities installed in 2018-2020		1 304 675	MWh
Additional power production in 2020 to 2017 considering reduction by capacities installed before 2018		**1 291 759**	MWh

Scenario "B": pessimistic	Installed power capacity in y.	Estimated Power production in 2020	Power production reduce in 2020 to 2017
2 011	4	4 565	69
2 012	158	181 237	2746
2 013	171	197 134	2 987
2 014	71	82 262	1 246
2 015	20	23 289	353
2 016	99	115 860	1 755
2 017	211	248 174	3 760
2 018	400	472 836	
2 019	400	475 212	
2 020	200	238 800	
Total		1 186 848	12 916
Additional power production in 2020 to 2017 by capacities installed in 2018-2020		1 186 848	MWh
Additional power production in 2020 to 2017 considering reduction by capacities installed before 2018		**1 173 932**	MWh

Scenario "A"	Installed power capacity in y.	Estimated Power production in 2020	Power production reduce in 2020 to 2017
2 011	4	4 565	69
2 012	158	181 237	2746
2 013	171	197 134	2 987
2 014	71	82 262	1 246
2 015	20	23 289	353
2 016	99	115 860	1 755
2 017	211	248 174	3 760
2 018	400	472 836	
2 019	400	475 212	
2 020	100	118 209	
Total		1 918 778	12 916
Additional power production in 2020 to 2017 by capacities installed in 2018-2020		1 066 257	MWh
Additional power production in 2020 to 2017 considering reduction by capacities installed before 2018		1 053 341	MWh

Continuation of appendix 4

Scenarios "A" & "B": additional solar PV power production in 2025		
Financial Assumptions:		
SPPs average yearly installed capacity in MW		**400**
Average energy output per 1 MW/p MWh		**1200**
Degradation factor (d)		**0,5%**
$Mt,el = St(1-d)^t$		
Total rated yearly Electricity generation MWh (*St*)		**480 000**

Period/y	Electricity generation (Mt, el)	Year
1	477 600	2018
2	475 212	2019
3	472 836	2020
4	470 472	2021
5	468 119	2022
6	465 779	2023
7	463 450	2024
8	461 133	2025

Scenario "B": optimistic	Installed power capacity in y.	Estimated Power production in 2025	Power production reduce in 2025 to 2017
2 011	4	4 452	182
2 012	158	176 751	7232
2 013	171	192 255	7866
2 014	71	80 226	3282
2 015	20	22 713	929
2 016	99	112 992	4623
2 017	211	242 031	9903
2 018	400	461 133	
2 019	400	463 450	
2 020	400	465 779	
2 021	400	468 119	
2 022	400	470 472	
2 023	400	472 836	
2 024	400	475 212	
2 025	400	477 600	
Total		4 586 020	34 017
Additional power production in 2025 to 2017 by capacities installed in 2018-2025		3 754 600	MWh
Additional power production in 2025 to 2017 considering reduction by capacities installed before 2018		**3 720 583**	MWh

Continuation of appendix 4

Scenario "B": tolerant	Installed power capacity in y.	Estimated Power production in 2025	Power production reduce in 2025 to 2017
2 011	4	4 452	182
2 012	158	176 751	7232
2 013	171	192 255	7866
2 014	71	80 226	3282
2 015	20	22 713	929
2 016	99	112 992	4623
2 017	211	242 031	9903
2 018	400	461 133	
2 019	400	463 450	
2 020	300	349 334	
2 021	300	351 090	
2 022	300	352 854	
2 023	300	354 627	
2 024	300	356 409	
2 025	300	358 200	
Total		3 878 517	34 017
Additional power production in 2025 to 2017 by capacities installed in 2018-2025		3 047 097	MWh
Additional power production in 2025 to 2017 considering reduction by capacities installed before 2018		**3 013 080**	MWh

Scenario "B": pessimistic	Installed power capacity in y.	Estimated Power production in 2025	Power production reduce in 2025 to 2017
2 011	4	4 452	182
2 012	158	176 751	7232
2 013	171	192 255	7866
2 014	71	80 226	3282
2 015	20	22 713	929
2 016	99	112 992	4623
2 017	211	242 031	9903
2 018	400	461 133	
2 019	400	463 450	
2 020	200	232 889	
2 021	200	234 060	
2 022	200	235 236	
2 023	200	236 418	
2 024	200	237 606	
2 025	200	238 800	
Total		3 171 012	34 017
Additional power production in 2025 to 2017 by capacities installed in 2018-2025		2 339 592	MWh
Additional power production in 2025 to 2017 considering reduction by capacities installed before 2018		**2 305 575**	MWh

Continuation of appendix 4

Scenario A	Installed power capacity in y.	Estimated Power production in 2025	Power production reduce in 2025 to 2017
2 011	4	4 452	182
2 012	158	176 751	7232
2 013	171	192 255	7866
2 014	71	80 226	3282
2 015	20	22 713	929
2 016	99	112 992	4623
2 017	211	242 031	9903
2 018	400	461 133	
2 019	400	463 450	
2 020	100	116 445	
2 021	50	58 515	
2 022	0	0	
2 023	0	0	
2 024	0	0	
2 025	0	0	
Total		1 930 963	34 017
Additional power production in 2025 to 2017 by capacities installed in 2018-2025		1 099 543	MWh
Additional power production in 2025 to 2017 considering reduction by capacities installed before 2018		1 065 526	MWh

Continuation of appendix 4

Scenarios "A" & "B": additional to 2017 solar PV power production in 2030		
Financial Assumptions:		
	SPPs average yearly installed capacity in MW	**400**
	Average energy output per 1 MW/p MWh	**1200**
	Degradation factor (d)	**0,5%**
	$Mt,el = St(1-d)^t$	
	Total rated yearly Electricity generation MWh (St)	**480 000**

Period/y	Electricity generation (Mt, el)	Year
1	477 600	2018
2	475 212	2019
3	472 836	2020
4	470 472	2021
5	468 119	2022
6	465 779	2023
7	463 450	2024
8	461 133	2025
9	458 827	2026
10	456 533	2027
11	454 250	2028
12	451 979	2029
13	449 719	2030

Scenario "B": optimistic	Installed power capacity in y.	Estimated Power production in 2030	Power production reduce in 2030 to 2017
2 011	4	4 342	292
2 012	158	172 376	11607
2 013	171	187 496	12625
2 014	71	78 241	5268
2 015	20	22 150	1491
2 016	99	110 195	7420
2 017	211	236 041	15893
2 018	400	449 719	
2 019	400	451 979	
2 020	400	454 250	
2 021	400	456 533	
2 022	400	458 827	
2 023	400	461 133	
2 024	400	463 450	
2 025	400	465 779	
2 026	400	468 119	
2 027	400	470 472	
2 028	400	472 836	
2 029	400	475 212	
2 030	400	477 600	
Total		6 836 750	54 596
Additional power production in 2030 to 2017 by capacities installed in 2018-2030		6 025 909	MWh
Additional power production in 2030 to 2017 considering reduction by capacities installed before 2018		**5 971 313**	MWh

Continuation of appendix 4

Scenario "B": tolerant	Installed power capacity in y.	Estimated Power production in 2030	Power production reduce in 2030 to 2017
2 011	4	4 342	292
2 012	158	172 376	11607
2 013	171	187 496	12625
2 014	71	78 241	5268
2 015	20	22 150	1491
2 016	99	110 195	7420
2 017	211	236 041	15893
2 018	400	449 719	
2 019	400	451 719	
2 020	300	340 688	
2 021	300	342 400	
2 022	300	344 120	
2 023	300	345 849	
2 024	300	347 587	
2 025	300	349 334	
2 026	300	351 090	
2 027	300	352 854	
2 028	300	354 627	
2 029	300	356 409	
2 030	300	358 200	
Total		5 555 437	54 596
Additional power production in 2030 to 2017 by capacities installed in 2018-2030		4 744 596	MWh
Additional power production in 2030 to 2017 considering reduction by capacities installed before 2018		**4 690 000**	MWh

Scenario "B": pessimistic	Installed power capacity in y.	Estimated Power production in 2030	Power production reduce in 2030 to 2017
2 011	4	4 342	292
2 012	158	172 376	11607
2 013	171	187 496	12625
2 014	71	78 241	5268
2 015	20	22 150	1491
2 016	99	110 195	7420
2 017	211	236 041	15893
2 018	400	449 719	
2 019	400	451 719	
2 020	200	227 125	
2 021	200	228 266	
2 022	200	229 413	
2 023	200	230 566	
2 024	200	231 725	
2 025	200	232 889	
2 026	200	234 060	
2 027	200	235 236	
2 028	200	236 418	
2 029	200	237 606	
2 030	200	238 800	
Total		4 274 383	54 596
Additional power production in 2030 to 2017 by capacities installed in 2018-2030		3 463 542	MWh
Additional power production in 2030 to 2017 considering reduction by capacities installed before 2018		**3 408 946**	MWh

Continuation of appendix 4

Scenario A	Installed power capacity in y.	Estimated Power production in 2030	Power production reduce in 2030 to 2017
2 011	4	4 342	292
2 012	158	172 376	11607
2 013	171	187 496	12625
2 014	71	78 241	5268
2 015	20	22 150	1491
2 016	99	110 195	7420
2 017	211	236 041	15893
2 018	400	449 719	
2 019	400	451 979	
2 020	100	110 752	
2 021	50	57 067	
2 022	0	0	
2 023	0	0	
2 024	0	0	
2 025	0	0	
2 026	0	0	
2 027	0	0	
2 028	0	0	
2 029	0	0	
2 030	0	0	
Total		1 880 358	54 596
Additional power production in 2030 to 2017 by capacities installed in 2018-2030		1 069 517	MWh
Additional power production in 2030 to 2017 considering reduction by capacities installed before 2018		**1 014 921**	MWh

Continuation of appendix 4

Scenarios "A" & "B": additional to 2017 solar PV power production in 2035			
Financial Assumptions:			
	SPPs average yearly installed capacity in MW		**400**
	Average energy output per 1 MW/p MWh		**1200**
	Degradation factor (d)		**0,5%**
	$Mt, el = St(1-d)^t$		
	Total rated yearly Electricity generation MWh		**480 000**
Period/y	**Electricity generation (Mt, el)**	**Year**	
1	477 600	2018	
2	475 212	2019	
3	472 836	2020	
4	470 472	2021	
5	468 119	2022	
6	465 779	2023	
7	463 450	2024	
8	461 133	2025	
9	458 827	2026	
10	456 533	2027	
11	454 250	2028	
12	451 979	2029	
13	449 719	2030	
14	447 470	2031	
15	445 233	2032	
16	443 007	2033	
17	440 792	2034	
18	438 588	2035	
19	436 395		
20	434 213		
21	432 042		
22	429 882		
23	427 732		
24	425 594		
25	423 466		

Continuation of appendix 4

Scenario "B": optimistic	Installed power capacity in y.	Estimated Power production in 2035	Power production reduce in 2035 to 2017
2011	4	4 235	399
2012	158	168 110	15 873
2013	171	182 856	17 265
2014	71	76 304	7 205
2015	20	21 602	2 040
2016	99	107 468	10 147
2017	211	230 168	21 736
2018	400	438 588	
2019	400	440 792	
2020	400	443 007	
2021	400	445 233	
2022	400	447 470	
2023	400	449 719	
2024	400	451 979	
2025	400	454 250	
2026	400	456 533	
2027	400	458 827	
2028	400	461 133	
2029	400	463 450	
2030	400	465 779	
2031	400	468 119	
2032	400	470 472	
2033	400	472 836	
2034	400	475 212	
2035	400	477 600	
Total		9 031 742	74 665
Additional power production in 2035 to 2017 by capacities installed in 2018-2035		8 240 999	MWh
Additional power production in 2035 to 2017 considering reduction by capacities installed before 2018		**8 166 334**	MWh
Scenario "B": tolerant	**Installed power capacity in y.**	**Estimated Power production in 2035**	**Power production reduction in 2035 to 2017**
2011	4	4 235	399
2012	158	168 110	15 873
2013	171	182 856	17 265
2014	71	76 304	7 205
2015	20	21 602	2 040
2016	99	107 468	10 147
2017	211	230 168	21 736
2018	400	438 588	
2019	400	440 792	
2020	300	332 255	
2021	300	333 925	
2022	300	335 603	
2023	300	337 289	
2024	300	338 984	
2025	300	340 688	
2026	300	342 400	
2027	300	344 120	
2028	300	345 849	
2029	300	347 587	
2030	300	349 334	
2031	300	351 090	
2032	300	352 854	
2033	300	354 627	
2034	300	356 409	
2035	300	358 200	
Total		7 191 337	74 665
Additional power production in 2035 to 2017 by capacities installed in 2018-2035		6 400 594	MWh
Additional power production in 2035 to 2017 considering reduction by capacities installed before 2018		**6 325 929**	MWh

Continuation of appendix 4

Scenario "B": pessimistic	Installed power capacity in y.	Estimated Power production in 2035	Power production reduce in 2035 to 2017
2 011	4	4 235	399
2 012	158	168 110	15 873
2 013	171	182 856	17 265
2 014	71	76 304	7 205
2 015	20	21 602	2 040
2 016	99	107 468	10 147
2 017	211	230 168	21 736
2 018	400	438 588	
2 019	400	440 792	
2 020	200	221 503	
2 021	200	222 617	
2 022	200	223 735	
2 023	200	224 860	
2 024	200	225 989	
2 025	200	227 125	
2 026	200	228 266	
2 027	200	229 413	
2 028	200	230 566	
2 029	200	231 725	
2 030	200	232 889	
2 031	200	234 060	
2 032	200	235 236	
2 033	200	236 418	
2 034	200	237 606	
2 035	200	238 800	
Total		5 350 931	74 665
Additional power production in 2035 to 2017 by capacities installed in 2018-2035		4 560 188	MWh
Additional power production in 2035 to 2017 considering reduction by capacities installed before 2018		**4 485 523**	MWh
Scenario A	**Installed power capacity in y.**	**Estimated Power production in 2035**	**Power production reduce in 2035 to 2017**
2 011	4	4 235	399
2 012	158	168 110	15 873
2 013	171	182 856	17 265
2 014	71	76 304	7 205
2 015	20	21 602	2 040
2 016	99	107 468	10 147
2 017	211	230 168	21 736
2 018	400	438 588	
2 019	400	440 792	
2 020	100	110 752	
2 021	50	55 654	
2 022	0	0	
2 023	0	0	
2 024	0	0	
2 025	0	0	
2 026	0	0	
2 027	0	0	
2 028	0	0	
2 029	0	0	
2 030	0	0	
2 031	0	0	
2 032	0	0	
2 033	0	0	
2 034	0	0	
2 035	0	0	
Total		1 836 529	74 665
Additional power production in 2035 to 2017 by capacities installed in 2018-2035		1 045 786	MWh
Additional power production in 2035 to 2017 considering reduction by capacities installed before 2018		**971 121**	MWh

Source: own calculation