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Environmental Technology & International Affairs

Assessing the potential of utility-scale PV power plants in Serbia: CBA of Kolubara A

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
Dipl.-Ing. Dr. techn. Mario Ortner

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Affidavit

I, **ANA STANARCEVIC BSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ASSESSING THE POTENTIAL AND VIABILITY OF PV POWER PLANTS IN SERBIA: CBA OF KOLUBARA A PV POWER PLANT", 70 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 the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

Serbia is at a turning point in terms of choosing its future energy strategy. The nation heavily depends on national coal reserves and hydropower resources. Based on known effects of climate change and ist devestating consequences, it is well known that this strategy cannot remain. Still, ever-present tension of globalization and national security remains in this case as well, pointing out that certain countries may indeed be threatened by the ever-growing complexity and interconnectedness of world´s countries. With the outbreak of Covid19 and ongoing wars, it is reasonable for countries to develop energy strategies that aren´t only sustainable and globally accepted, but that are also mostly built around their national capabilities in terms of resources and expertise. In line with arguments of sustainability, cost-efficiency, morality, but also strategic independency, renewable sources show as the ultimate solution. Due to encouraging country-specific conditions, but also positive global trends, PV technology in Serbia seem to be taking momentum now. This thesis examines the technological, technical, economic, social, and political settings in order to better understand the factors that affect the potential and viability of utility-scale PV. Additionally, it will examine the state of PV technology in Serbia at the moment and provide projections about the future. (edit)

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Abbreviations

PV	Photovoltaic
WHO	World Health Organization
PM	Particulate Matter
EU	European Union
IRENA	International Renewable Energy Agency…

Acknowledgements

The thesis has been written as the final jewel of my wonderful time of the ETIA studies, and is dedicated to my home country, written with hope I will never lose my curiosity and motivation to discover the unknown.

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1. Introduction

The following chapter introduces the topic of the thesis by explaining background and motivation of the author, describing state of the art, and leading to a definition of objectives and research questions. Lastly, literature review and methodology will be discussed shortly.

1.1. Serbia – time for a healthy twist?

Serbia finds itself at the crossroad of its future energy path. The country is still considered a transitioning economy, being heavily dependent on domestic coal, and to certain extent, its hydropower resources. As visible bellow, around 60% of electricity production relies on low-quality lignite coal, rest being mainly attributed to Serbia´s waters. Although hydropower experienced changes in output in the last couple of months, coal dependency is evident, and share of renewables involved remains low (IEA Statistics, 2022). In today´s times, it is more than evident that that such electricity mix cannot remain, having several arguments to proves so.

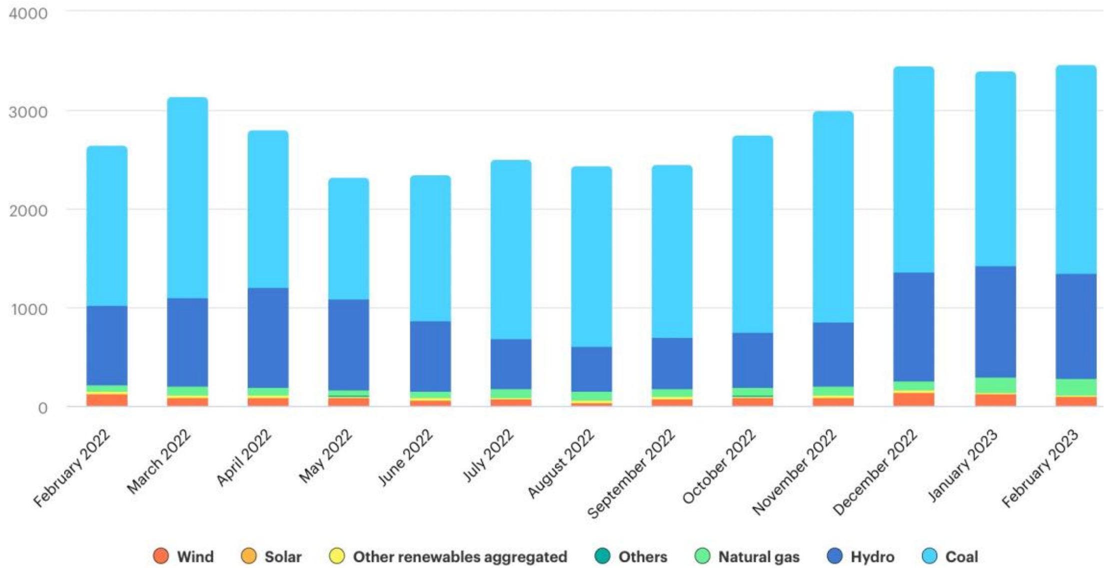

Figure 1: Serbia´s electricity mix

Most importantly, combustion of coal and other fossil fuels leads to human and environmental degradation. By fact, Serbia is home to some of the most polluting coal plants in Europe, and today, it is considered 5th most polluted country in Europe when it comes to levels of air pollution (IQAir, n.d.). Winters in Serbia get unbearable, with smog covering most of visible view. It is known that particulate matter of small diameter harms humans most strongly, causing respiratory issues, damaging cardiovascular health, leading to allergies and irritations in humans, etc. Quality of life gets significantly reduced as daily activities become limited – people cannot go for a longer walk and cannot think of having sports in the nature. What is worst, is that such levels of pollution not only limit human activities, but also lives. WHO data show to what extent pollutants as PM and SO2 lead to premature deaths in Serbia (WHO, 2019). Secondly, profitability and reliability of this mix may take a twist. Namely, coal indeed is a limited resource, and if it continues being overexploited, country, remaining hold on such energy structure, may indeed be left with nothing (Djurisic, 2022). High demand and limited reserves lead to increased prices, so that attractivity of such way of energy production remains questionable. Moreover, the quality of coal is seen to drop over time, leading to further adjustments in profitability calculations. Next, morality question also comes into picture. Could current generations really allow themselves to use up all of coal reserves, and to what extent are they responsible for the environment they are leaving to future generations, are some of the questions that arise. Opinions are different, with most prevailing one laying in the exact definition of sustainability. Considering all arguments, is it evident that coal dependency cannot have a long-lasting future in Serbia.

Even without consent on above-mentioned issues, being an EU candidate country, accessing the Energy Community in 2006 (EC, Serbia, n.d.), and choosing to enhance its integration with Europe and rest of the world, Serbia ought to take certain steps regarding its energy patterns. Rules and standards are ever-expanding, and liberalization and sustainability of energy systems in Europe are unnegotiable. Still, ever-present tension of globalization and national security remains in this case as well. As a growing body of literature suggest, national security of certain countries may indeed be threatened by the ever-growing complexity and interconnectedness of world´s countries (Ripsman, 2005). With the outbreak of Covid19 and ongoing wars, Russo-Ukrainian being in this context the most relevant one, energy markets experienced severe changes, ultimately limiting global supply chains. In such an unpredictable world, it is reasonable for countries to develop energy strategies that aren´t only sustainable and globally accepted, but that are also mostly built around their national capabilities in terms of resources and expertise. Serbia doesn't have abundant resources of natural gas, so that this option isn't considered. Getting public acceptance and necessary technology for nuclear power would take precious time and efforts (Djurisic, 2022). Still, as a complementary technology, it can be of use at a certain point, as Serbian government is already assessing (Spasic, 2022).

However, in line with all arguments, namely sustainability, cost-efficiency, morality, but also strategic independency, renewable sources show as the ultimate solution. They give apromising outlook and hope. For Serbia as such, this points to hydro, wind, and solar power resources. Due to encouraging country-specific conditions, but also positive global trends, I have gradually built personal interest in potential of PV technology in Serbia.

To sum it up, my motivation to explore this topic is tied together with hope that Serbia will successfully transition to a more sustainable economy, further integrating into European and world community, and most importantly, effectively contributing to healthier lives for all its citizens.

1.2. Sun’s Sustainable Enlightenment

We know Sun as a massive, luminous ball of hot gas, that has been radiating energy for billions of years in time. Based on historical records, we know that humans used this energy as early as from the 7th century B.C. They were, with help of magnifying glass, using sunlight to light fires, torches, etc. They were positioning homes and adjusting activities, so that they could profit from its heat and rays (S. K. Nag, 2022). Although Sun´s energy is now already in use for centuries, as I see it, we are about to benefit from it for the second, crucial time. The Sun has illuminated our lives in the past, brightening our homes and surroundings, and now it has the power to enlighten us, guiding our path towards sustainable development.

Attractivity for investing in and dealing with solar energy is present for some years already. Developments in solar technology and industry have brought about drastic decreases in investment and operative costs of PV systems. IRENA shows that costs for power generation in 2020 accounted for 10 times less than in 2010 (IRENA, 2023). As for PV systems there aren’t ´´fuel costs´´, specific costs are reasonably relatively lower. Knowing this, one can understand the background for positive trends in PV installations. As one can see from the figure bellow, the amount of PV facilities increased continuously over time from 2015 until 2021in the EU countries. We can see several possible scenarios for the period until 2025, from which all point to further increases in numbers. Historical data is showed in grey, low scenario in blue, middle scenario in orange, and high scenario in yellow color.

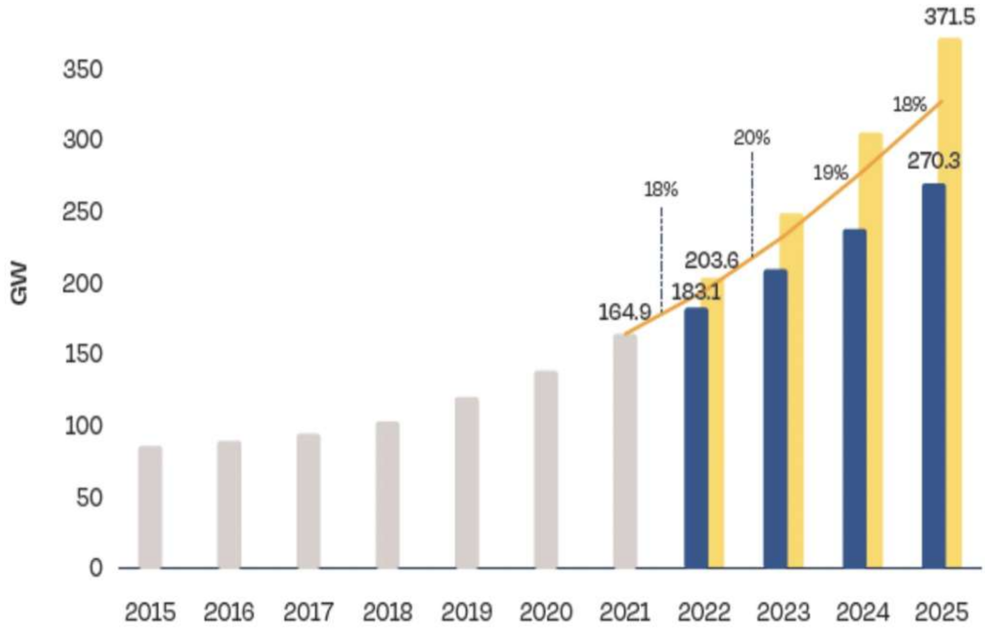

Figure 10: Historical and expected capacity of PVPP in the EU (SPE, 2020).

However, by far, highest installations of PV technologies can be seen leaving the EU zone. According to the IEA, China is the undisputable global leader of renewable energy expansion, holding more than a third of cumulative solar PV capacity. Although the country has been experiencing turbulences in the growth due to changes in internal policies and regulations relevant for the sector, the growth of Asia´s giant is undisputable. Following China, US and India aren't lacking much behind, with total investment of both countries expected to reach USD 25 billion over the course of 2022-2027, when it comes to solar PV manufacturing (IEA, 2022).

Not only has PV technology rose drastically in absolute values but has also made changes in the share of (renewable) energy sources used worldwide. By fact, PV expansions amount to over 60% of all current expansions of RES, and utility-scale power plants appear as the least costly option for usage. As visible in the graph bellow, by 2027 solar PV is expected to get tripled from now, reaching 2350 GW of installed capacity, surpassing coal, the traditional leader, in in 2027, natural gas in 2026 and hydropower in 2024. Over the course of next five years, annual solar PV capacity additions will grow intensively. It is worth mentioning that IEA also predicts a growth in distributed solar PV, such as that on rooftop buildings (IEA, 2022). It is clear – the momentum for PV took turn.

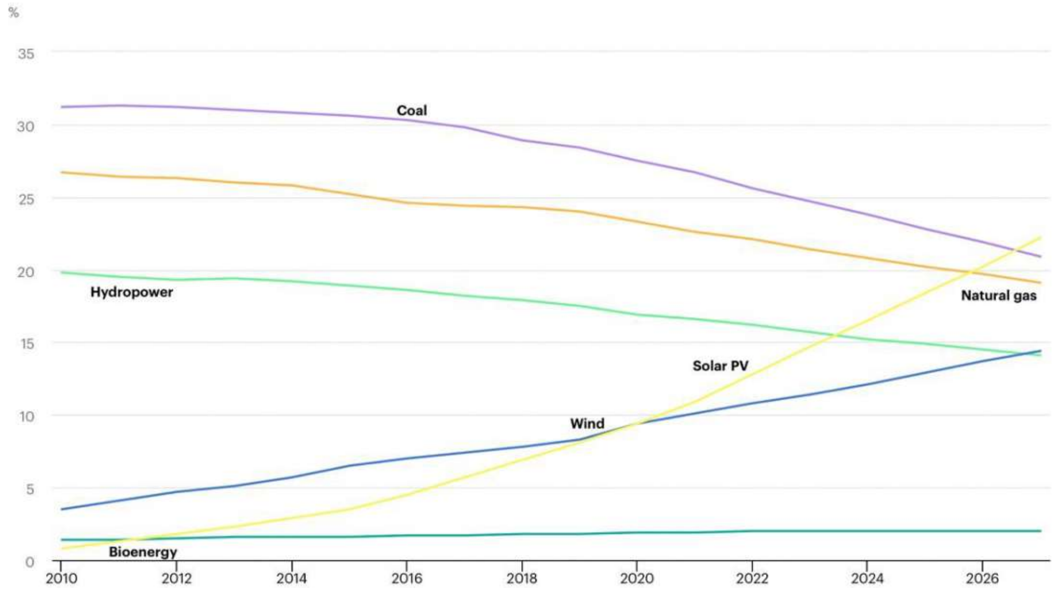

Figure 18: Share of power capacity for the period 2010-2027 (IEA, 2022).

1.3. Objective and Research Questions

The objective of this thesis is to assess the potential and viability of utility-scale PV power plants in Serbia for the purpose of electricity generation. Based on the assumption of the author, potential will be assessed based on technological advancements of PV technology in this context. Next, technical, economic, legal, and social factors for Serbia will be observed, so that viability of such facilities could be evaluated. To complement the second part of the examination, a CBA analysis will be included. The context set for the framework is the ongoing energy transition in Serbia, whose main goal is increasing the share of renewables in its national energy mix. The objective of this thesis ultimately imposes two following research questions:

1. *What is the potential and viability of utility-scale PV power plants in Serbia?*
2. *To what extent is PV project ´´Kolubara A´´profitable?*

1.4. Literature Review and Methodology

Will be added

2. Trend Analysis: How does the technology develop?

The following chapter focuses on understanding of relevant technology trends in context of utility-scale PV power plants intended for electricity generation. First, PV technology will be introduced, and a typical such power plant will be presented, together with related concepts of importance. Next, state of art will be discussed in detail, pointing to most promising ongoing and predicted advancements. This way, the essential basis for carrying out the rest of the analysis, and drawing conclusions for the future technological potential, will be created.

2.1. What are utility-scale PV power plants?

The understanding of these facilities comes with the understanding of the PV effect, and their constitutive components. It was in 1839 when Edmund Becquerel, a French scientist and Nobel laureate, discovered it (S. K. Nag, 2022). It is defined as the production or change of potential between two electrodes that are separated by a suitable electrolyte, or other substance, when the electrodes are illuminated in an unsymmetrical way (Copeland, 1942). In other words, PV effect explains the ability of certain materials to convert light into an electric current. For it to take place, PV cells and sunlight must interact. PV cells are usually made of two different types of semiconductor materials, a p-type, and an n-type, to which impurities (boron, phosphorus, etc.) have intentionally been added during the manufacturing process. Because of these impurities, regions with excess and deficient electrons are created, further building p-n junctions – basis of the effect. The crucial point in process happens when such surface interacts with sunlight. Sunlight, being composed of photons – small bundles of electromagnetic energy, touches cells which then absorb these photons. In such a way, energy from the photon is transferred to atoms of the semiconductor materials. This received energy initiates a flow of electrons, and at the junctions, a depletion region is being created- a region that now has a deficit of electrons and holes, but a strong electric field, which, acting as an insulator, and facilitating the movement of charges, and ultimately, under all conditions, enabling the generating of an electric current (Željkovic, 2018). The photovoltaic effect is illustrated in the figure bellow, where one can see showing solar irradiance interacting with a layered photovoltaic cell.

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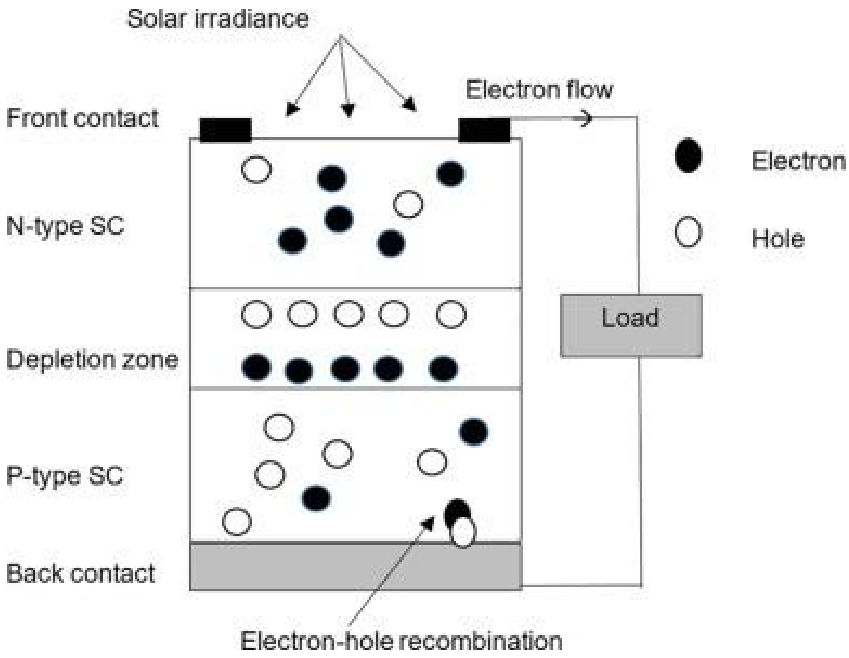

Figure 22: The Photovoltaic effect (Mellit, 2022).

Photovoltaic systems can be divided into stand-alone solar power systems, grid-connected solar power systems, and hybrid systems (connected to another renewable energy source). Grid-connected PV systems that are intended to deliver relatively bigger amounts of energy into the grid, and simultaneously aren't largely used up locally, are called (large-scale) PV power plans, or in industry more often referred to as utility-scale PV power plants. These facilities are reliable and more cost-efficient than small-scale systems. Based on the exact type, they can include different parts and connecting installations. Exact equipment and linking mechanisms depend on the system size, place, and application. There are several main constitutive units (Željkovic, 2018).

First and most important, they include the PV modules. These consist of multiple interconnected PV cells, thereby directly converting solar radiation into electricity through the PV effect. Modules may be connected in series, increasing the voltage. Their performance decreases over time due to different causes, some of them being effects of humidity, temperature, solar irradiation, or voltage bias effects. Also, possible reasons could imply from quality of materials used, or the whole of manufacturing process. As maintenance has relatively low effect on degradation rate, it is advisable that reputable module manufacturers are chosen. Manufacturers of such modules are primarily based in Asia (China, Japan, India, etc.) Degradation rates range from 0.3% - 1.0 % per year. Furthermore, fine quality PV modules are expected to last 25 – 30 years (IFC, 2015).

Module mounting (or tracking) systems are another important element. These securely tie PV modules to the ground. They can be fixed or tracking. Fixed mounting systems keep PV modules at a fixed, carefully chosen, tilt angle. They are mainly fabricated from steel, aluminum, and some also from wooden elements, and are simpler and cheaper than their alternative, and therefore very popular in the emerging solar markets. On the other hand, tracking systems are used to include additional support, following theSun as it moves, and thereby representing only moving parts used in PV installations. They consist of either single or dual-axis trackers, with first one altering either orientationor tilt-angle, and second one both. Depending on exact conditions, such systems can increase energy yield by up to 27% and 45% percent each, respectively. What always holds is – the simpler the construction, the lower the extra yield, and the lower the maintenance costs and efforts. (IFC, 2015).

Inverters are needed for the crucial part of process regarding grid connection – converting the DC electricity into AC electricity. Still, they can also perform several other fucntions, such as optimizing the voltage across strings, monitoring string performance, providing protection and isolation in case of irregularities, etc. They are usually divided into two groups - central and string inverters. The first represent a such configuration, in which many modules are connected in a series, with strings then being connected in parallel to the inverter. They are reliable and simple, yet mismatch losses are possible. In contrast, string inverter configuration uses multiple inverters for multiple strings, providing more operative and emergency support. Anyhow, inverters should be provided with controllers to measure the grid output and provide the MPPT functionality – technique used to optimize the power output (IFC, 2015).

Transformers are instruments characteristic for utility-scale PV power plants (connected to grid). They deal with adjustments (step up/step down) of voltage levels. We consider two groups in context of PV, namely distribution and grid transformers. The first are used to step up the voltage taking the output from an inverter to the extent required for the distribution network. If the plant shall first be connected to the transmission network, then the second type is used, allowing for even higher voltage levels. In such a way, losses due to long-distance transportation can be decreased. They are highly durable, having long operational lifespans with proper maintenance levels (IFC, 2015).

Bellow one can see the visualization of a typical process performed by utility-scale PV power plants. As discussed, the process consists of main elements discussed above, and additional connecting installations.

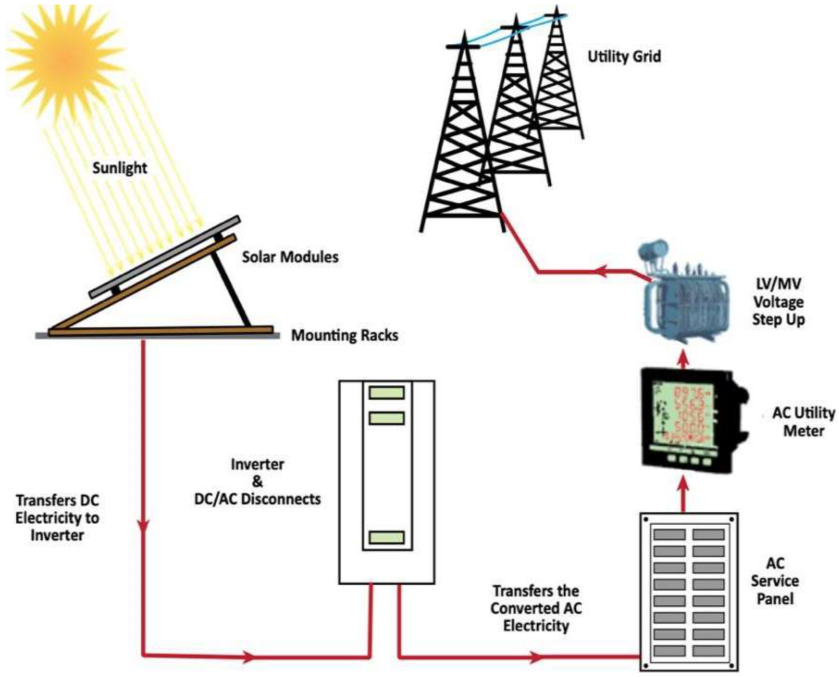

Figure 23: Process of a typical utility-scale PV power plant (IFC, 2015).

Additionally, batteries can be introduced as another integral part to the system, yet optional. They are used to storage energy, and are present by almost all stand-alone power systems, with growing importance to utility-scale systems, as well. Their integration can lead to several benefits for the system, namely – they can mitigate power fluctuations, improve system stability, provide backup power during blackouts and other grid disturbances, and overall, enhance reliability and resilience of the electricity supply. They function on the base of electrochemical conversion – with charging, the electrical energy is transformed into chemical, and with discharging, the other way around. Most often, they are made of lead, nickel, and lithium. Lead ones are reliable and relatively affordable, but of limited use. Nickel batteries are more expensive, but offer longer useful life, higher energy density, and faster charging. Lithium batteries represent most advanced type of technology, and are, to an extent, more costly. (Željkovic, 2018)

It is important to understand that necessity of certain components may also vary over time and place.

2.2. Technology advancements

2.2.1. PV (cell) materials

Advances in PV technologies have developed extensively over time and continue to do so. The market is full of different alternatives, with all manufacturers aiming to increase conversion efficiency and reduce costs.

We distinguish between several types, some of them being – crystalline photovoltaics and thin film. Crystalline photovoltaics represent traditional technology, with monocrystalline being invented in 1955 as the original PV technology, and polycrystalline entering the market in 1981. The first one is composed of cells cut from a single silicon, being the purest one, while the later of a whole block of silicon crystals that have been melted together. They are relatively costly, their performance degrades with higher temperatures, and they prefer direct access to light, although diffuse light can be taken use of as well (Indulkar, 2017). Yet, importantly, they show higher efficiency and power outputs than the alternative technology, with monocrystalline having 20% and the polycrystalline 15% efficiency (Awasthi, 2020). Thin film technology uses thin deposit of silicon, and more exotic materials such as amorphous silicon, cadmium telluride and copper indium diselenide. They are flexible and lightweight, a good option in hot climates, more affordable, and often a better option for low light/diffuse light conditions. Still, their efficiency remains lower, amounting from 9-15% (Indulkar, 2017).

After first and second generation, presented in the paragraph bellow, third generation cells, as referred to in several reports, are being developed. They provide efficiency of around 23% in laboratory conditions, and they incorporate perovskite solar cells, organic solar cells, and quantum dots solar cells. They all use different materials, structures, and parts of different manufacturing processes, yet, promising and worth a mention.

In contrast to above-mentioned technologies that rely on specific materials and structures, biohybrid cells focus on harnessing of a biological process. This technology was first reported by researchers in Vanderbilt University, stating they developed a new type of cells that combines organic and inorganic matter. They used PS I (photosystem I) – large protein complex found in the membrane of thylakoid, to reconstruct the ordinary natural process of photosynthesis in such a way, to achieve superior efficiency in conversion of solar energy. Inorganic materials are remaining the same as in more conventional cell types. PS II, second most important photosystem of photosynthesis, has also been researched for usage. Overall, through this technology, conversion to electrical energy becomes much more effective, showing improvements of up to 1000 times higher effectivity than those of conventional technologies. Although still limited to the laboratory scale, promising future awaits with their development (Riaz, 2021).

Important to note that aside from emerging materials, there are also new mechanisms that increase PV module efficiency (e.g. bifacial solar panels).

2.2.2. Concentrated PV

Yet, some believe PV cells to have limited room for performance improvement, especially without additional significant costs. In this context, another type of technology gives promise, namely the concentrated photovoltaics. CPV mainly operate with multi-junction solar cells, cells that are made of multiple layers of semiconductor materials and represent one of the best ways to maximize the yield of conversion efficiency by focusing sunlight with use of different concentrators. They are classified into high and low concentration groups, Fresnel lens, parabolic dish and non-imaging dish being under the first group, and parabolic trough, compound parabolic concentrators, and quantum dot under the second. This way, relatively cheaper optical devices can replace the need for expensive cell materials, decreasing overall manufacturing costs. Next, performance is increased, with one study showing a peak efficiency value of up to 40%. This is seen as one of the main advantages of this technology. Lastly, CPV decreases spatial needs - as PV modulesstart being used more efficiently due to use of concentrators, space is saved. Yet, it is worth mentioning that there are certain challenges in developments as well, some of thembeing in context of diffuse light conditions, cell temperatures, soiling, reliability, and durability (Ali Ejaz, 2021).

Perhaps most important topic to deal with CPV is the topic of thermal management and cooling techniques. While achieving higher efficiency and other mentioned benefits, higher temperatures of cells are also a received result from the operation. CPV processes may lead to overheated cells, further leading to issues, such as disturbances in efficiency, higher rates of degradation, thermal stresses, etc. It is therefore important to address this issue with more attention. Techniques could be active or passive, with some of the most common mechanisms being: PCM, hydraulic, heat pipes, liquid immersion, micro-channels, etc. (Ali Ejaz, 2021).

Hydraulic cooling, as the name suggests, takes use of a hydraulic fluid as a coolant. Temperature decreases of up to 40°C were observed in CPV systems using water as a coolant. This technology offers high thermal conductivity and capacity, but salt accumulation shows up as one of the drawbacks. Heat pipe cooling includes usage of heat pipes that are employed to keep the temperature of solar cells constant. They are simple to include and provide a big range of heat transfer. Still, this system faces difficulties with corrosion, high cost, non-condensable gas generation, and complex design. Next, liquid immersion cooling could be employed. In this way, systems are cooled utilizing liquid immersion techniques, such as the use of dielectric liquids. The benefits include zero electricity usage and the capacity to transfer heat from the PV cells' front and back surfaces. There are issues with cost and design, as well as worries about salt buildup. Micro-channel cooling uses micro-channels as heat sinks, and achieved operation of PV cells with a concentration ratio of 500 suns at a low temperature of 29.3°C. Still, maybe the most important type of cooling techniques is the PCM cooling, which integrates phase changing materials into the cooling system. This technique provides passive heat exchange, zero electricity use, and a significant amount of heat storage capacity at a constant temperature. Some of the drawbacks of the technology include their high price and volume requirements (Ali Ejaz, 2021).

Research from 2022 identified CPV-TE-PCM configuration as the most superior one, showing a 111.4% higher energy efficiency than that of a CPV system without cooling techniques. This kind of system employs PCM cooling technique and thermoelectric technology, which additionally allows for conversion of waste heat generated by a CPV system, thereby producing even more electrical energy. Yet, it is worth mentioning the cost differences as well, which put CPV-TE-PCM and a CPV system without cooling techniques in such a relation, where the first shows cost of about 147% higher amount than the latter (Yusuf, 2022).

One is clear, all studies imply that there is an immense potential and certainty that with further adjustments of PV concentrator materials and design, CPV may keep expanding as the leading technology for harnessing sun´s energy. This is especially true in the context of large-scale facilities, that aim for bigger electricity amounts. More research is expected and awaited.

2.2.3. Smart grid

Smart grid stands as another important advancement when it comes to potential expansion of utility-scale PV power plants. Increase in population and their demands, together with ever-growing needs for efficiency and sustainability, have put pressure on conventional grids used since decades. As a result, networks have developed to that extent, that we may now give them the name of ´´smart grids´´, in that case. The term is considered to stand for an intelligent electricity network that enables clear and reliable connection of all stakeholders (generators, consumers, suppliers, etc.) in a way that electricity is supplied in an efficient, sustainable, economical, and secure way (ETP, 2010). In other words, it is more than a single technology - rather a smart system. It therefore makes sense that its origins lay in developments of first networks. Installations of smart meters also represent a steppingstone in the context (ETHW, 2022).

Table 1: Difference between a Smart and a Conventional Grid (Yu, 2009)

Smart Grid	Conventional Grid
Two-way real-time communication	One-way communication
Distributed system of power generation	Centralized for power generation
Interconnected network	Radial Newtork
A large number of sensors included	A small quantity of basic sensors included
Digital operation	Mechanical operation
Automatic control and monitor	Manual control and monitor
Wide range of control	Limited control
Security and privacy concerns	No security or privacy concern

Advancements made lead to several benefits. Consumers are provided with a more reliable electricity supply, as smart grids commonly have a self-healing characteristic. Namely, as they can monitor in real-time, they can detect abnormalities, even anticipatea problem, and react quickly in a way that major blackouts or similar disturbances are avoided. They isolate the problem, and deal with it in proper time. Next, they include automatic metering which provides the two-way communication structure. In that way, distributors can allow for a more accurate billing system, and consumers can track their consumption and plan it in an economical way (Butt, 2020).

Perhaps the most important in context of utility-scale PV power plants is the ability to allow for a more decentralized power generation. Such plants, but also ones from other renewable energy sources, tend to often be in remote areas. Sometimes it is not even possible and economical to connect such electricity spots to the main transmission system, so there is a need for micro-grids. Such an intelligent system, as the smart grid system is, can now handle bigger amount of data, and could allow for integration of more resources to the network. This is considered the most important and critical advancement for the future of renewable electricity. Still, there is lot of room for further research and advancement, especially in context of privacy. Most of them lays in the usage of Internet of Things and Big Data, directly important for big power plants that are to be made (Butt, 2020).

2.2.4. Grid-scale storage

Research in energy storage technologies is ongoing and have been evolving steadily since the early 20th century. Most significant benefit remains in the ability to store surplus power generation for later use and in acting in critical times such as after a system failure or breakdown (Indulkar, 2017). Yet, these technologies today perform various other functions, some of them being power quality improvement, energy management and protection, better integration of non-dispatchable renewable energies, etc. When it comes to utility-scale PVPPs, they may or may not be connected to an energy storage device. Common as a support to such systems are mechanical (e.g. pumped hydro storage), electric (e.g. supercapacitors), and electrochemical (e.g. batteries) mechanism (Massague, 2020).

In this context, most discussed in public are batteries – electrochemical devices in which energy is stored chemically, and then, through reduction and oxidation reactions, eventually transformed into electrical energy. We can generally distinguish between four groups available in the market, namely lead-acid, alkaline, molten salt, and lithium-ion. Lead-acid batteries area affordable and offer simple scalability and modularity, their nominal cell voltage is 2.04V, and are often a reasonable option for renewable generating systems. Yet, they have a limited specific energy and lifespan. Alkaline are also relatively inexpensive and of similar performance, yet they are characterized by a limitedcell voltage of around 1.3V, it addition to which self-discharge could be noticed. On the other hand, two other groups represent relatively newer and better performing options. Molten salt ones show nominal cell voltages of around 2.6V, high cyclability, and limited self-discharge. Still, one significant drawback is present, namely the fact that they need operating temperature over 300 degrees Celsius and preheating periods. Lastly, lithium-ion batteries show an excellent lifespan and a nominal cell voltage of up to 3.7V, modularity and low self-discharge., being relatively more costly than alternatives (Massague, 2020).

Indeed, lithium batteries are by fact the most popular EST used with large-scale PV power plants. It is evident that they help prevent grid disturbances, and allow for frequency and voltage regulations, which are most important issues to tackle in context of growing integration of RES into grids. In fact, they are highly compatible with majority of grids. Current grid codes are such that they require high power and medium energy, and these types of batteries stand out as very convenient. Science says that for future grid code requirements, fast response storage will be necessary, and super capacitors may be the most preferred option, but this still isn´t the case (Massague, 2020). Yet, as briefly mentioned, cost of such mechanisms present a significant drawback, mainly because of potential resource limitations of lithium. Next, an efficient collection and recycling scheme is required. It is known that extraction and disposal of such materials poses a certain threat to the environment, therefore creating pressures for its potential increasing market growth (Chen, 2020). Yet, this type of batteries still prevails in usage and showed performance.

What remains evident, is that additional in-depth investigations are necessary, especially in context of electrochemical devices, and that more materials need to be considered, with examples being potassium-ion and Li-S batteries. Furthermore, preferred positions of placing such instruments need to be determined with more precision. In any case, as the IEA report shows, these technologies will expand immensely. The agency's Net Zero Scenario calls for a 44-fold increase in deployed grid-scale battery storage capacity to 680 GW between 2021 and 2030. Up from 6 GW in 2021, roughly 140 GW of capacity is generated in just 2030. Annual additions must rise dramatically, achieving an average of over 80 GW per year over the span of 2022–2030, if we are to remain on keeping up with the targeted scenario (IEA, 2022). This could be seen on the graph bellow, that clearly shows these projections.

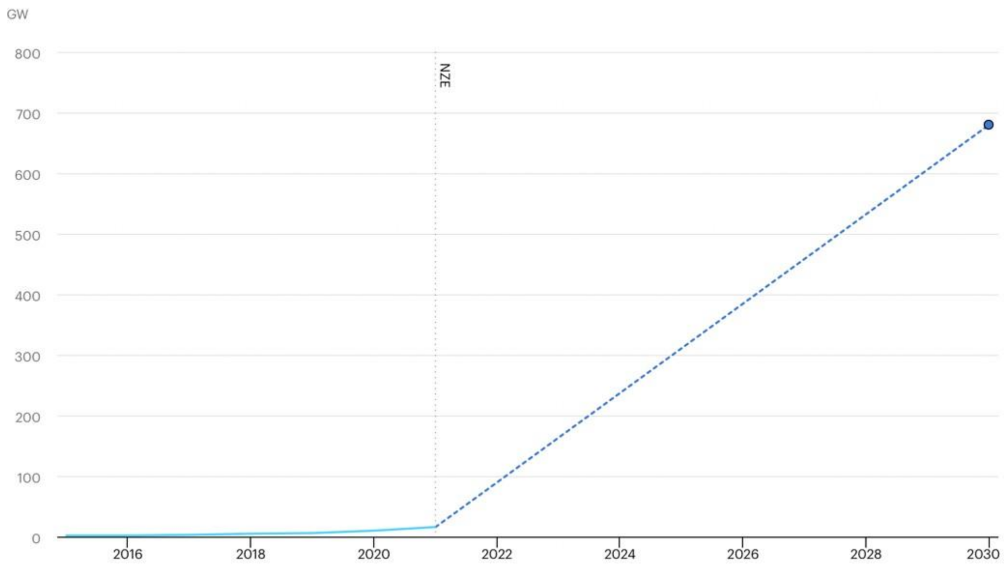

Figure 24: Installed grid-scale battery storage capacity in the Net Zero Scenario, 2015-2030 (IEA, 2022).

2.2.5. Complementarity of RES

Interesting to consider when assessing potential and viability of PV systems is also their complementarity with other renewable energy sources, as conditions may offer possibility for additional increases of individual attractivities. In this context, combination of solar and wind power should be considered. It is expected from these two variable resources to be leaders of renewable electricity, and luckily, synergy could be achieved through their contrasting patterns of behavior.

By fact, wind is on average stronger nights than days, and stronger in winter than in summer. This is exactly opposing the solar patterns, which show strongest irradiance and benefits during summer days. This therefore implies that their installed capacities could be planned optimally in a way which considers these different behaviors (Djurisic, 2022). The figure bellow shows average monthly electricity generation from PV and wind power plants in the last 10 years in the region of OECD Europe. Seasonality differences of two lines are clear, and very nicely present the potential of complementary use of these two resources.

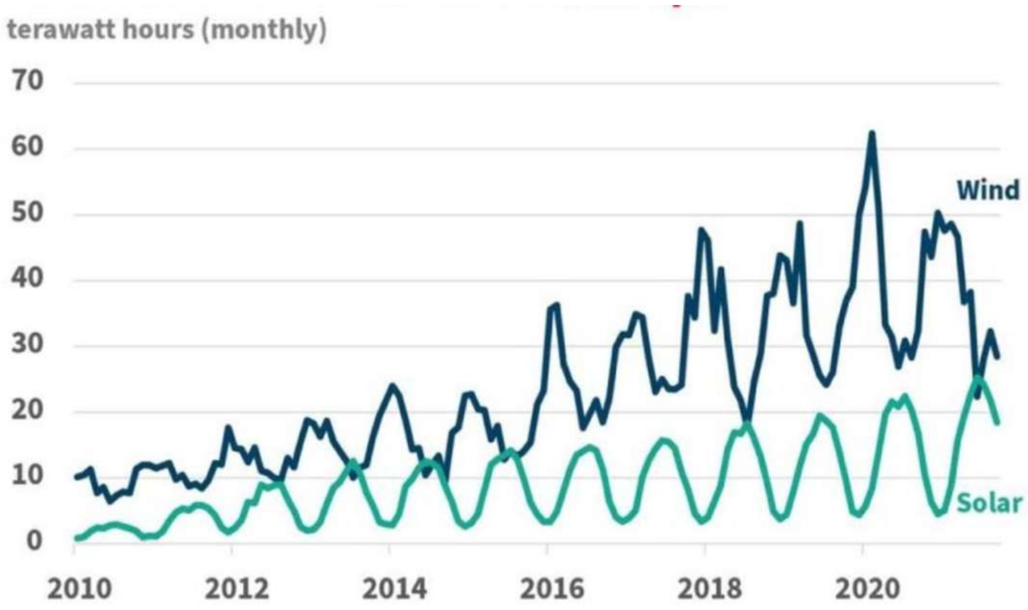

Figure 25: Wind and Solar Electricity in OECD Europe (Djurisic, 2022).

Comprehensive research suggests that PV-wind hybrid systems are mostly present in India, Iran and China, and that batteries represent most widely used auxiliary component to such a system (Mazzeo, 2021) It is worth mentioning that there are other options of hybrid compositions, such as PV-hydro or PV-biomass, yet this option remains most present in literature.

2.2.6. Agrivoltaics

Another practice that gained importance in recent years is the agrivoltaic technology, also called ´´dual use´´, ´´agri-solar´´etc. With increasing world population, demand for energy and food rise almost in the same pace. What is obvious, is that eventually, there is competition for land – one must choose whether land will be used for food or energy production. In 1980, agrivoltaic concept emerged, and brought solutions to this problem. The system namely represents a structure in which synergy of PV technology and agricultural production is achieved. The exact structure can vary depending on the particular goal of agricultural practices, with main ones being presented in the Figure 9. Not only that this system reduces land conflicts, but it also increases land use efficiency. Still, there are certain factors needed to be considered, so that negative effects are excluded, some of them being elevation, spacing, tilt and choice of PV panels. When going further into detail, one can also differentiate different type of crops that are to be grown, with preferred ones being those that don't necessarily need constant full sun. It is obvious that different climatic conditions also contribute in a different way to success of such systems. Until now, there hasn't been a model developed that could calculate for the optimal panel arrangement for a given area and crop. Most recent studies point to this issue as the direction in which further research needs to go, for this promising structure to further expand in the world (Sarr, 2023).

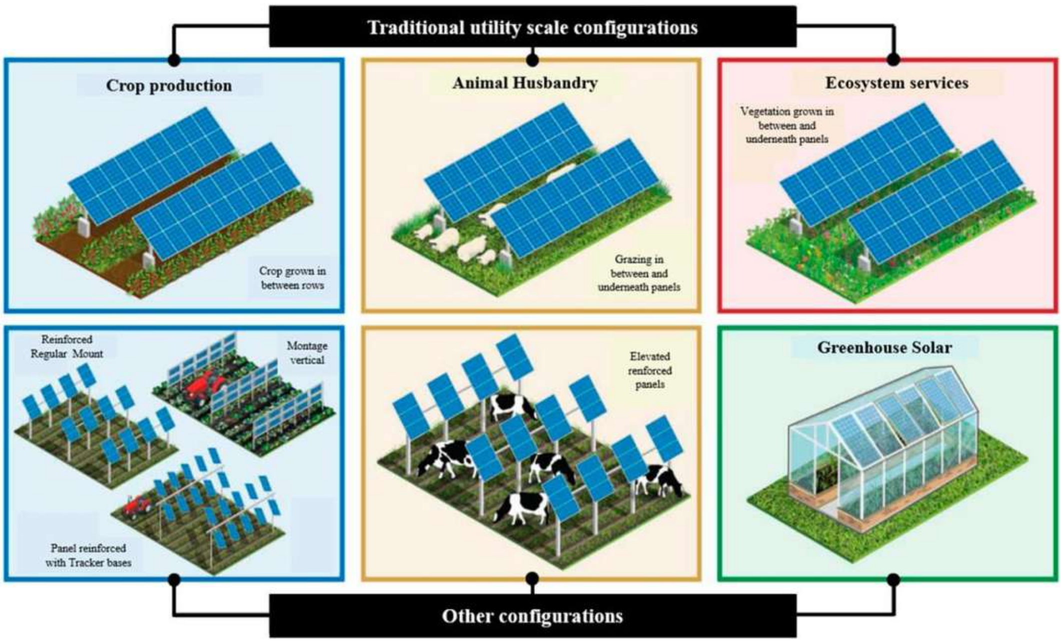

Figure 26: Different agrivoltaic systems (Sarr, 2023).

3. Technical Analysis: What are the conditions Serbia is offering?

After exploring most important trends from author´s view, specific analysis for the area of Serbia may begin. In order to assess (technical) potential of utility-scale PV in Serbia, one must investigate relevant technical conditions Serbia as a country is offering. Most of technical factors can be adjusted during some of the production phase - planning, installation, or operation. Yet, certain country-specific offer less flexibility, thereby making themselves interesting for the analysis. For the purpose of this thesis, author chose to investigate solar radiation, land availability and grid infrastructure and capacity in Serbia in more detail. Next, lithium reserves will be included, as a factor of potential relevance. Lastly, technical conclusions will be presented under the Technical Outlook subtitle.

3.1. Introducing Serbia

Serbia is a country positioned in Southeast, bordering Hungary to the north, Romania and Bulgaria to the east, North Macedonia to the south, and Croatia, Bosnia & Herzegovina, and Montenegro to the west. Country has a population of about 6,7 million people, excluding the administrative province of Kosovo & Metohija. Capital of the country is Belgrade, with around 1,7 million inhabitants. The most represented religion in Serbia is orthodox Christianity, holding the share of around 85% people, with the rest 15% being split between Roman Catholic Christianity, Islam, and other (Serbia, 2023) Documented existence of Serbians dates as of early 7th century AD, making the country´s history long and rich, yet turbulent. Its advantageous central position has put the countryin variety of wars, continuously leading to detrimental consequences for population, environment, and economy. Yet, the specific central position also gave Serbia an access to a variety of markets and transportation channels, making it a hub for regional commerceand economic activity, providing local businesses and industries with a substantial marketbase. All the history and geography is ultimately also reflected in Serbia´s (geo)political setting.

The country is a land characterized by a diverse topography. Its norther part lays within the Pannonian Plain, being mostly flat, while the rest of the country belongs to mountainous regions – Dinaric Alps, Carpathian and Balkan Mountain and the Rhodope Mountains. This creates variations in altitudes, ranging from 29m up to 2655. Being a landlocked country, most important characteristic regarding water surfaces is the river Danube, and several big lakes (Palić, Đerdap, etc.) (Lukovic, 2015).

According to Bureau of Statistics of Serbia, country´s economy has experienced visable growth in recent years, with a steadily increasing GDP (Statistics, 2023). In 2021, Serbia's GDP reached approximately $63,8 billion, reflecting a positive trend fueled by various sectors. The country's biggest sectors include manufacturing, agriculture, and services. As for manufacturing, automotive production presents a prominent contributor. The agricultural sector is also of importance, with most commonly cultivated crops such as wheat, corn, and fruits. Also, the services sector that encompassing finance, tourism, and information technology, has been seen to expanding rapidly (Bank, 2023). These diverse sectors contribute to Serbia's economic stability.

When it comes to RES, potential is considered to be significantly bigger than what is being used by now. Serbia´s total estimated technically usable potential of renewable energy sources is measured for 5.65 Mtoe per year. Out of all sources, biomass has the highest potential for use, accounting to around 3.448 Mtoe, and followed by hydro power with 1.679 Mtoe, out of which a large percentage has already been used up in large hydro power plants. Next is solar energy with 0.240 Mtoe, geothermal energy with 0.180 Mtoe, and wind energy with 0.103 Mtoe (Dragovic, 2019).

3.2. Solar Radiation

In this context, it is important to understand the simple difference between solar radiation and irradiance. The first one refers to the spectrum of different wavelengths (from ultraviolet to infrared) that sun is emitting and transmitting from its surface to our planet. On the other hand, irradiance refers to intensity of electromagnetic radiation incident on a surface of one square meter. Solar irradiance is an important notion, as, due to absorption, diffusion, and reflection of particles, not all solar radiation reaches Earth. The terms are usually being measured in W and W/m² respectively (Indulkar, 2017). Measuring of solar radiation is challenging, yet for today´s state of science to certain precision possible. Solargis, company aiming to be most reliable supplier of solar data, developed a model for assessing solar irradiance for different regions and countries of the world, that as a base takes satellite images and atmospheric data (Solargis, 2023). This data is open and available to all, and as part of the ESMAP report, published by the World Bank in 2020. Results of this report will be presented in this and next subsection, namely Solar radiation, and Land use.

Although there are many parameters important for the solar energy industry, GHI (global horizontal irradiation) stands out as the primary one, focusing on shortwave radiation that is received by a horizontal surface. GHI has in this report being used to describe the theoretical potential for PV power generation, namely the long-term distribution of solar resource, or in other words, the ´´amount of fuel´´ a country has for generating PV electricity at certain locations. In this context, it is interesting to compare such potential for Serbia and Germany, one of the Europe´s leaders in solar energy developments (Madsen, 2019). Serbia measures average theoretical potential (GHI) of 3.68 kWh/m^2, while Germany, significantly lower, a theoretical potential (GHI) of 2.98 kWh/ m^2 (The World Bank, 2020).

Important to consider is also the duration of sunshine hours. One research found that the longest duration of sunshine hours appears to be in lowlands of Vojvodina (norther part), including river valleys in central and southern parts. This shows that with increased altitude duration of total insolation decreases (Lukovic, 2015). Next, divergence in radiation over seasons should also be considered. Serbia seems to have a seasonality index, index used for seasonal fluctuations description, of 2,99 for the region of Serbia. Putting it into perspective, South Africa has the value of 1.2, having very stable electricity production throughout the year. On the other hand, Germany´s value reaches 4.4, indicating that in the toughest winter conditions less than a quarter of electricity can be generated than in the most promising summer month (The World Bank, 2020). This implies Serbia finds itself in a relatively acceptable position for PV generated electricity when it comes to seasonal variations. Yet, the country still faces economic and technological challenges of certain extent, opening doors to hybrid systems and overall increases in efficiency for generated renewable electricity.

However, analyzing only solar radiation as such would be naïve, so PVOUT (kWh/kWp) had to be introduced – a measure of the power output that can be achieved by a typical PV system. In this way, we can consider the impact of air temperature, terrain horizon, albedo, but also configuration, soiling and other factors. Including all these factors, the report issued values for the, now, practical PV potential of world´s countries. This practical potential is considered for three levels, with the level 0 considering no technical limitations that may further follow. Again, Serbia shows off as more attractive than the European leader (The World Bank, 2020). Another research continues adding that the highest amountof electricity generated based on the solar potential of Serbia can be achieved through single axis tracker technology, capturing most of the sunlight (Djurisic, 2022).

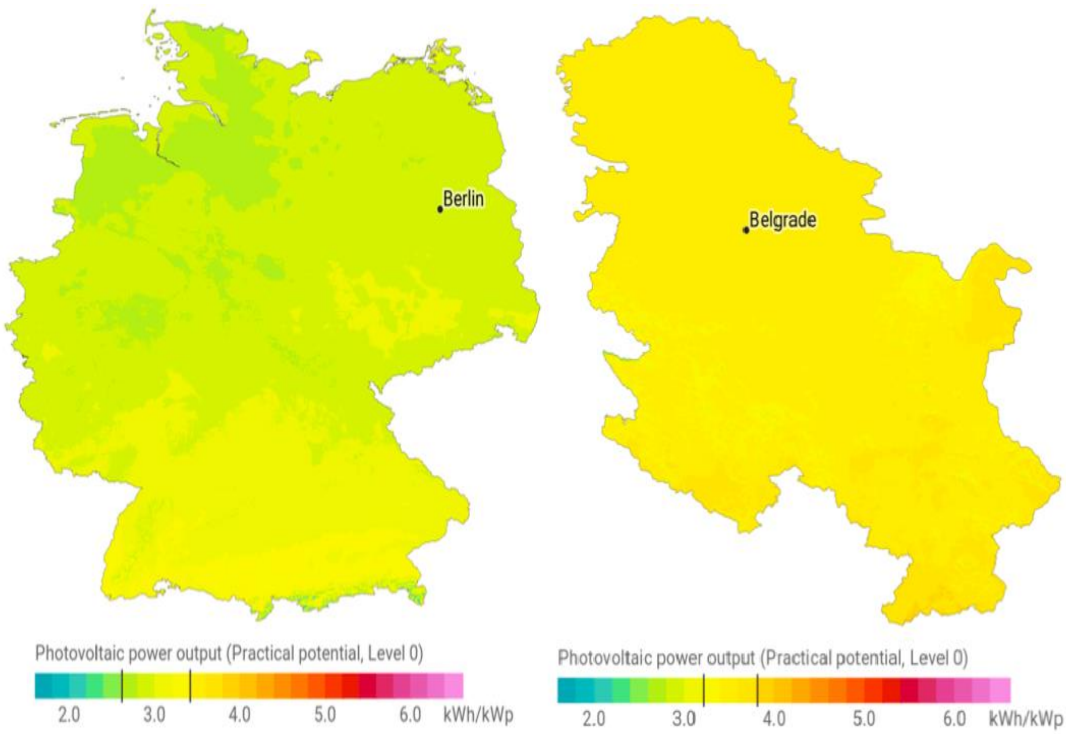

Figure 27: Practical potential on level 0 for Germany (left); Practical potentialon level 0 for Serbia (without K&P province) (right) (The World Bank, 2020).

3.3. Land Availability

The ESMAP reports, after the introduced level 0, also considers two other levels – 1 and 2. Both emerge from the perspective of utility-scale PV power plants. The first one excludes land with physical or technical land-use constraints. In more detail, it excludes complex terrain, area where the land surface isn't desirably flat or uniform. Secondly, it excludes large water bodies and compact forests. Lastly, it excludes uninhabited areas with no or extremely scarce settlements, as well as intra-urban areas where density of urbanization is more than 50%. On this level, Serbia again scores a better result than Germany, having a practical potential for level 1 of 3.52 kWh/kWp, whereas Germany showed a value of 2.96 kWh/kWp. (The World Bank, 2020). The second level introduces further factors, namely it excludes zones that may be unsuitable due to regulatory land-use restrictions. Those considered are protected areas with any status and croplands.

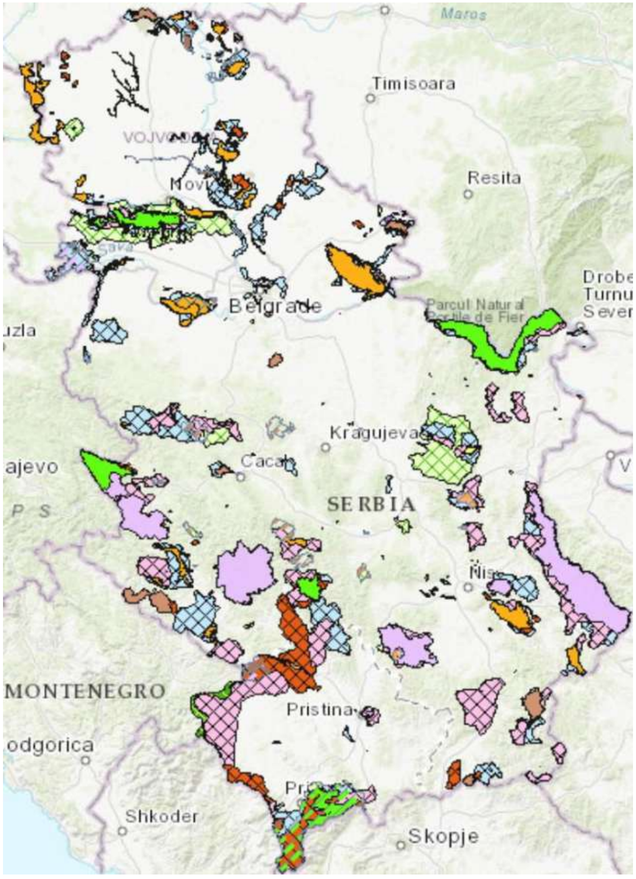

Figure 28: Protected areas in the Republic of Serbia (Djurisic, 2022)

Combining solar radiation and land availability (including all introduced limitations above), one can see the distribution of suitable land in Serbia in more detail. It is evident that 39,4% of Serbia´s land shows characteristics highly suitable for establishments of PVPPs, mainly with a PVOUT of above 3.4. Arguably, more than 39,4 % of land could be used with necessary arrangements with relevant (local) authorities. Here in question come also the agri-voltaic PPs, from which both electricity and agriculture benefits are achieved.

kWh/kWp	39.4 %	84.1 %	100.0 %	of evaluated area
over 3.6	5.4 %	8.4 %	10.4 %	
3.6 — 3.4	31.8 %	73.1 %	83.1 %	
below 3.4	2.3 %	2.6 %	6.5 %	

Practical potential: Level 2 Level 1 Level 0

Figure 29*: Distribution of PV power output (The World Bank, 2020).*

3.4. Grid

Grid infrastructure represents another crucial limiting factor when it comes to PV expansions and their integration into the electrical system. Existing networks in Serbia have been built in times of a vertically integrated structures, and today experience certain difficulties in this context.

Access to grid spatially varies and taken as such has been taken together with conditions of solar radiation and land availability, and for this purpose, specific regions in Serbia have been evaluated for utility-scale PVPP suitability. Results can be seen in the table below. The greatest potential for construction can be seen at the devastated land in the Kolubara region, as well as in the Drmno coal mine region. Also, ash pits and other land usurped by thermal power plants stood as convenient. Important to note for understanding is that the fourth column assumes that half of the capacity will be realized on sun-tracking structures and half on fixed south-oriented structures, and that the last column expects all theoretical capacities to be built. Lastly, all the data considers newly produced PV panels (Djurisic, 2022).

Table 2: Potential for construction of ground PVPPs in Serbia (Djurisic, 2022)

Region number	Region	Surfacearea (km^2)	Specific annual production of photovoltaic systems on ground structures (MWh/MWp)	Technical potential forthe installation of photovoltaic systems on ground structures (MWp)	Annual production of photovoltaic systems on ground structures (GWh/year)
1	West Backa	2488	1412	50	71
2	North Backa	1784	1417	200	283
3	North Banat	2328	1416	200	283
4	South Backa	4026	1423	200	285
5	Middle Banat	3257	1424	250	356
6	Srem	3485	1413	50	71
7	South Banat	4246	1426	120	171
8	Macva	3270	1399	80	112

9	Belgrade	3234	1418	150	213
10	Kolubara	2474	1416	3000	4248
11	Danube	1250	1402	50	70
12	Branicevo	3857	1423	800	1138
13	Zlatibor	6140	1459	150	219
14	Moravica	3016	1411	200	282
15	Sumadija	2388	1415	200	283
16	Pomoravlje	2614	1426	100	143
17	Bor	3507	1483	600	890
18	Raska	3923	1412	250	353
19	Rasina	2668	1408	200	282
20	Nisava	2728	1472	350	515
21	Zajecar	3624	1479	300	444
22	Toplica	2231	1469	50	73
23	Jablanica	2770	1473	500	736
24	Pirot	2761	1494	300	448
25	Pcinja	3520	1526	400	610

When it comes to historical developments of the network in Serbia, one can name several important dates. The country experienced electrification in year of 1893, which was followed by the first transmission line achieved in 1903, namely the one from hydroelectric power plant Vučje to the city of Leskovac. Further important connections appeared in 1938, after thermal power plant Vreoci was put into operation. Lines of 60kV voltage have been created between the facility and cities of Belgrade and Arandjelovac. Yet, it was the ending of the World War Two that brought developments of this regard to the country. As transmission lines depend on many factors, among other economic facilities and development, industrialization that started at the time significantly enhanced electricity distribution and transmission. First transformer substation was built in 1952, and in 1957, 110kV networks of all republics of former Yugoslavia have been connected in an efficient manner. What is maybe most important is the year of 1958 and forming of a separate entity, namely *´´Elektroistok´´*, that in 2005 ultimately evolved as EMS *(´´Elektromreža Srbije´´),* country´s present transmission system operator (EMS, 2023). In 1991, EDS *(´´Elektrodistribucija Srbije´´)*, country´s present distribution system operator, has been formed (EDS, 2023). Today, main goals of both transmission and distribution system operators remains in allowing for a secure and reliable transportation of electricity.

3.4.1. Current infrastructure and capacity

Today, the transmission system in Serbia, employing around 1350 people, consists of transmission lines, cables, transformer stations and certain facilities of voltage levels of 400kV, 220kV and 110kV, excluding transformer stations 110/x kV, which belong to the distribution system. The transmission system connects two sides – the production facilities and the distribution system and customer´s facilities (e.g. industrial complexes). Additionally, the system is of course connected to networks from neighboring countries. (EMS, 2023). As of 31.12.2022, EMS reported owning transmission lines in amount of 542 with the total length of 11,058.16 km with the AP of Kosovo & Metohija. The PE also reported 85 transformer substations in the same area (EMS, 2022). Furthermore, according to author´s personal knowledge, as of today, there is no PV power plant that is connected to the transmission system. On the other hand, the distribution system encompasses distributions lines of around 165,337.96 km in length and has more than 30 PV power plants of different, relatively smaller sizes and voltages, that are already connected to thesystem (EDS, 2022) Certainly, there is more capacity for integration of new PVPPs, the questions that remain are how, and what then?

An important aspect to look at when planning RES integration is to understand where Serbia stands in the context of smart grid technologies. EMS, being the crucial actor in this process, ought to work on flexibility and enhancements of the network. Its aims can be reflected in the fact that the PE became the member of the ENTSO-E – association established for creating unified standards and criteria for the operation of transmission systems in all parts of Europe (ENTSO-E, 2023) Through its membership, EMS works on carrying out association's initiatives, ranging from creation of smart grid infrastructure, employment of advanced technologies, addressing data and cybersecurity challenges, etc.

3.4.2. Planned infrastructure and capacity

To start with, EMS plans to work on automatic voltage regulation, counting for 35 transformers of such a setting in the next few years. Moreover, an expert team suggested to also implement remote automatic adjustment of the reference voltage values that would be obtained from the SCADA/EMS system – software used to monitor and manage electrical power systems. Next, the EP works on expanding the WAMS system – real time monitoring system that provides wide-area situational awareness and allows for automatization of processes. The system also enhances grid stability and reliability and takes use of PMUs – phasor measurement units. Serbia currently has them at several locations already, and EMS works on increasing that number. Furthermore, EMS works on positioning of emergency poles – structures used to provide urgent, temporary support in emergency situations. Perhaps most directly connected to integration of RES is the digitalization that the EMS is aiming for. Namely, there is an envisaged pilot project, through which DS Pancevo 1 would be fully digitalized. If successful, this know-how would be spread on other parts of the network (EMS b), 2020).

Further in this context, and reported by the Balkan Green Energy News, EU plans to support Serbia with loans and grants for power interconnections and smart metering. Namely, EU approved a donation of EUR 17 million for power interconnections with Bosnia and Herzegovina and Montenegro, and introduction of an advanced system for remote reading of electricity meters, called Advanced System for Remote Meter Reading Phase 1A. Both projects together are worth EUR 81 million and are financed through loans. The investment in the Advanced System for Remote Meter Reading Phase 1A is valued at EUR 40 million, with an almost EUR 8 million grant from the WBIF. The project will be financed through a EUR 23 million loan obtained from the EBRD (Todorovic, 2022)

Still, as written in the EMS´ development plan, main focus on the national level lays in dealing with radially fed distribution transformer stations of 110/X kV. These improvements would most significantly facilitate further RES integration in the system. According to the mentioned report, simulations for the year 2030 pointed to possible disruptions due to the planned radial connection of solar plant ´´Srednje kostolacko ostrvo´´to the DS Drmno. In this regard, EMS plans to define better connection ways, and enhance flexibility for future connections of similar kind. Furthermore, on the 110 kV voltage level, EMS also plans to invest more in interconnection of transmission and distribution system, and in general, connection of upcoming facilities into the transmission network (EMS b), 2020).

Next, EMS plans to replace all 220 kV lines as its useful life reaches end. In the future, these pathways will be used for 110 kV and 400 kV voltage level networks, with only those 220 kV remaining, that economically/technically shall not be displaced. On the broader level, big part of planned investments lays in a 400 kV line that is to be expanded to the region of western and central Serbia, leading to better connectivity with neighboring countries, but also to higher supply security for consumers of the region. This plan represents part of the Trans-Balkan Corridor project (EMS, 2022).

When it comes to possible connections, EMS has more than 30 PVPP requests which are in connection process, ranging from 40 MW to 1000 MW installed capacity,with Solar Park in Kladovo being the leader in values (EMS, 2023). By fact, connection requires have increased from 4.8 GW to 20 GW in the last two years, or in other words, for two and a half times more than the total capacity of all power plants in Serbia (Energy, 2023) On the figure bellow, one can see number and positions of current requesting plants.

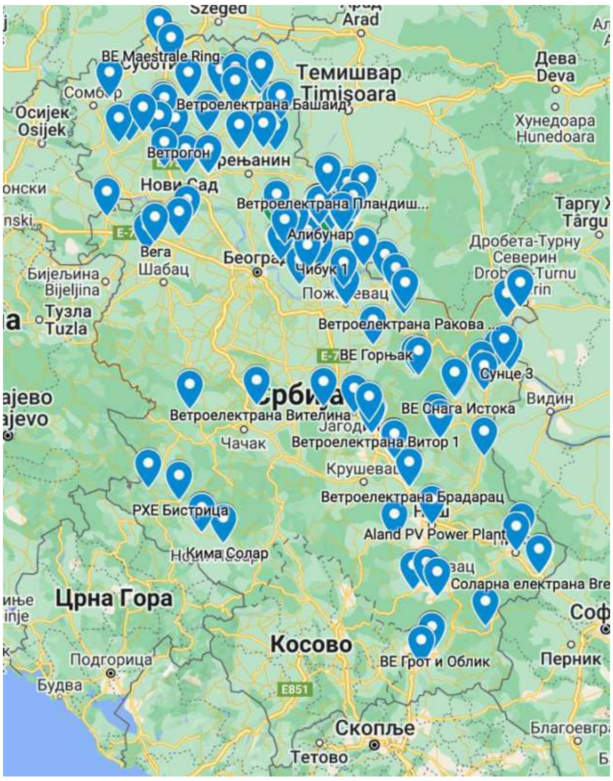

Figure 30: PVPPs requesting connection to the transmission system, may 2023

What´s more, it is evident that trend has roots for being continued, when looking at those that are yet to be developed. According to Balkan Green Energy News, the Serbian government has started a process of choosing a strategic partner for developing 1 GW of solar power plants and 200 MW of battery storage. The respected partner will be in charge of building the solar power facilities and batteries, instructing the EPS on how to run them, and turning the facilities over after two years (News, 2023) Furthermore, IEL, a French company has requested a spatial planning document for their 90 MW PV project in northern Serbia (Todorovic, 2023)

On the other hand, due to their incompatibility with aims and standards of today, certain unsustainable power plants started being in the processes of dismissal. Table bellow shows 2 examples, one of them being the relevant power plant of the cost benefit analysis in chapter 7.

Table 3: Dismissal of PPs in ownership of EMS (EMS b), 2020)

Facility	Planned year of dismissal	Installed power (MW)
TP Kolubara A (A3)	After 2020. (latest 2023)	65
TP Kolubara A (A5)	After 2020 (latest 2023)	110
TP Morava	After 2020 (latest 2023)	120

3.5. Lithium Reserves

As discussed in the second chapter, lithium batteries offer several advantages as additions to PPs, but also in other sectors, such as e-mobility. BloombergNEF estimated in of the articles that demand for lithium may grow eightfold over the next 11 years. Additionally, it has been stated that Serbia has such reserves, that if managed to be extracted properly, have the possibility to efficiently support the continent in competing with Asian developments. It is still challenging to rank Serbia on the base of its resources due to lack in data, yet estimated amounts received big attention in the last years (Savic, 2019). Interesting to add are the events that took place last year. Namely, the mining giant – Rio Tinto, aimed to exploit Serbia´s lithium resources under the project ´´Jadar´´, spending a minimum of EUR 1,2 just for the land of interest. Although certain projections account for about 2,100 created construction jobs and an infusion of about EUR 200 million into

Serbian supply chains, the deal has been stoped in April 2022. Environmentalists and majority of citizens have stood against the project, mainly pointing onto potential environmental concerns (Dragojlo, 2023)

3.6. Technical Outlook

Serbia has a technical potential for construction of PV power plants on its territory (without the AP of K&M) that amounts to about 24 GW, exceeding current needs for electricity in the country (Djurisic, 2022). This has also been presented over relevant determining factors of author´s choice. It is evident that there is enough capacity in the grid to handle steadily growing electricity production. Yet, it is also up to grid operators to enhance infrastructure and technologies even further, so that security and reliability of supply won't be jeopardized. With stated plans of the operators, it is visible the country aims on preventing possible disruptions and wants to work on further RES integration into the system, with utility-scale PVPPs being part of the equation. Regarding energy storage, it is evident that country has material potential which could bring extensive benefits, theoretically even in a form of a national (lithium) battery factory. One way or around, Serbia has an outlook that is promising.

4. Legal and Strategic Analysis

Without strategic and legal frameworks that support RES, we are hardly to witness successful developments. World has functioned on the base of fossil fuels since decades, so it is now necessary to meaningfully support projects in relevant industries. Being a helpful example, Australia illustrates well how even a developed country, one of the biggest world'seconomies, may be stuck in a dead-end due to its lack of necessary policies.. Research from 2020 shows that only 6% of the country´s total energy consumption was, at the time, derived from renewables (Hong Li, 2020). Serbia, being a country with significantly lower economic capabilities appears to need even stronger assistance and motivation in creating progress in this context. Indeed, research focused on solar energy in Serbia pointed to regulatory features, including both legal and institutional framework, together with governance, as one of the major challenges for implementation of RES projects in Serbia (Bjelic, 2021).

Being an EU candidate country, Serbia aims to align its regulations with the one from the Union, so that these, together with other international agreements, treaties, and initiatives, strongly affect Serbia's renewable energy development in the country. Even active participation in the international flora itself leaves Serbia with an opportunity to learn from other countries' successful deployment strategies. On the national level, local regulations most directly influence the PV landscape. The existence of inclusive and supportive policies provides stability for solar investment, increasing investor confidence and facilitating PV growth. Conversely, lack of clear and favorable regulations, such as complex permitting processes, can discourage solar investment and hinder technology adoption. The legal framework ruling RES in Serbia has made remarkable progress in recent years. The following chapter will present the international, EU, and national legal and strategic context, that directly or indirectly (as part of broader, RES context) influences PV developments in Serbia, with important events being listed chronologically. Next, influence of these regulations will be assessed.

4.1. Existing Frameworks

In the following paragraphs, existing strategic and legal frameworks will be discussed, from the broad international to the national level. Lastly, new amendments to the Law on Use of Renewable Energy Sources will be discussed.

4.1.1. International level

On a very broad level, it can be seen that PV technology stands behind the SDG 7 – affordable and clean energy for all (UN, n.d.) Energy it provides is expected to be increasingly affordable, sustainable, and reliable, and to some extent, it already is. Being a member to the UN since 2001, Serbia attaches high importance on the implementation of the 2030 Agenda, and an attainment of the SDGs, taking various activities at the national level to allow for appropriate implementation (Serbia M. , n.d.) Highlighting the necessity for employment of renewable energy sources, these have a limited apparent influence on the employment of PV technologies in Serbia. Yet, the global trend of RES integration certainly shapes the base and path.

Serbia has been a party to the UNFCC since 2001, and to the Paris Agreement since 2017. In 2022, Serbia submitted its revised NDCs, thereby increasing the target of emission reduction from 9.8% to 13.2 % compared to 2010 levels, or 33.3% compared to 1990 levels, by 2030. This new target includes key economic sectors, one of them being energy production (UNDP, 2023) Again, these aims are mainly of declarative nature, and cannot necessarily be directly brought to the relevance of PV technology itself.

Serbia was also a founding member to IRENA – International Renewable Energy Agency, and to this date, participates actively in the assemblies of the organization. IRENA provides a platform for sharing best practices, policy advice, and technical assistance in the field of renewables, which is of certain importance to Serbia. Furthermore, data that IRENA provides about capacities, investment costs and other countrys´experiences, gives Serbia a great overview and base for its own developments in context of RES, and PV technology. Beginning of 2023, DG of IRENA offered Serbia expert and technological support in defining the instruments for detecting and mapping RES potentials anddefining concrete steps for implementation of short-, medium- and long-term plans (SEE Energy News, 2023)

Lastly, on the international level, it is important to note regional cooperation initiatives. Serbia has participated in various of them aimed at promoting renewable energy and cooperation among countries in the region of Western Balkans. These initiatives, regional working groups and research collaborations further facilitate knowledge sharing, policy harmonization, and possible joint projects in the RES sector, including PV.

4.1.2. EU level

EU as an institution influences Serbia´s regulations and strategies most strongly. With the European Council´s decision in 2012, Serbia has been declared as a candidate country for the EU membership. That and adopting of the National Strategy for the Accession to the EU formally recognized Serbia´s path for the next years. The country has begun the process of harmonizing its national regulations with the one from the EU. This, above other, also includes aligning national with EU environmental and energy efficiency regulation, and regulation ruling necessary increasing share of renewables, among other, also capturing PV technologies (Bjelic, 2021).

Energy transition has been high on EU agenda for some time already. One of the first examples of action on this level was the Directive on promotion of electricity produced from RES in the internal electricity market in 2001 (Bjelic, 2021). The Directive set indicative targets and an overall EU target for the share of renewable electricity consumption (EUR-lex, Document 32001L0077). In 2008, it was the EU´s Climate and Energy Package that wasof significance. It included the 20-20-20 targets, namely 20% reduction in GHG emissions, 20% increase in the share of RE in the final consumption, and 20% improvements regarding energy efficiency (AirClim, 2023). It was followed by the Lisbon Treaty from 2009, that laid the base for subsequent initiatives and actions that latertook place. Treaty itself was focusing on reforming the institutional framework of the EU and enhancing its decision-making process (EUR-lex, Document 12007L/TXT). Another important milestone was the Renewable Energy Directive from 2009, that specified that by 2020, overall share of 20% of renewable energy should be reached on the level of EU consumption. Individual member states had to establish themselves reasonable national targets, including specific electricity targets, for the overall goal to be achieved, which was binding (Bjelic, 2021). In 2015, the European Energy Union was established, securing its member states a secure, fully integrated, an efficient internal market, aiming to decarbonize the economies and support research and innovation beyond countries´ borders (EC, 2023). This restructuring was also a significant step in context of smoother cooperation with non-EU states, involving energy infrastructure projects, energy trading and more effective dialogue on energy-related issues. Three years after, in 2018, Clean Energy Package emerged, together with, among other, the revised, now-called, Renewable Energy Directive II (Bjelic, 2021). The CEP updated targets from 2008, increasingthe share for renewable energy sources in the EU´s energy mix to 32%. It made clear thata possible review for an even further increase is possible in 2023. (CEP, 2023). What came out as different as before, is that by this package, member states have to commit totheir national targets in their national plans. The progress will be evaluated by the EC bythe end of year of 2030. Lastly, the latest efforts came along with the Green deal – most ambitious milestone made Its goal is to reach carbon neutrality by 2050 through, amongother ways, a better integration of renewables to the grid and enhancements of regional networks. Moreover, the deal also incorporates the Green Agenda for Western Balkanand the Economic and Investment Plan for the Western Balkan. (Bjelic, 2021)

Still, one of the crucial events in context of strategic and legal milestones relevant for employment of renewable energy in Serbia is the Law on ratification of the Treaty establishing the Energy Community (Bjelic, 2021). The treaty was signed in 2005, and has been in force since 2006, defining EC as an organization having the aim to extend the EU´s internal energy market principles to the contracting parties (Energy Community, 2023) Indeed, the EC as a body represents a critical factor influencing Serbia´s legal and policy framework. Through ratification, Serbia agreed to reach a certain percentage of final energy consumption from renewables by 2020. Furthermore, a consistent reform of national governance framework became another task. This, throughout years, resulted in creation of new national renewable energy policies, revision of energy law, adoption of energy action plans, alongside new institutional infrastructure built to support the process (Karova, 2009). Overall, it is evident that EC also promotes liberalization, encourages competition, and fosters cross-border energy trade, allowing Serbia to benefit from the free movement of energy, attract investments, access new technologies, etc. Furthermore, Serbia can participate in discussions on policies, exchanging mechanisms and knowledge.

4.1.3. National level

It is one year before the ratification of Energy Community Treaty, with the Energy Development Strategy from 2005, that Serbia already expressed the intention of aligning its energy development with the European path. The strategy already then recognized the importance and potential of renewables in the country, suggesting measures as financial incentives and adoption of programs to frame the RE developments. Yet, this was assessed as more of a declarative form of commitment. Maybe the most important document brought on the national level, being a consequence of Serbia´s membership in the Energy Community, is the **National Renewable Energy Plan** from 2013. The plan sets a target of 27% for the share of renewables in final consumption by 2020, and actions to reach it. The relevant entity to monitor and report on the progress is the relevant ministry for energy. Next, in the year of 2015, ten years after the initial one, the **new Serbian Energy Strategy** came into place, and it focused on the period until 2025, with projections for 2030. Now, potential of renewables is one of the top priorities of action. Lastly, in 2017, the **Program of Energy Strategy implementation** from 2017 until 2023 has been created, and concrete measures, activities, indicators, and precise particularities of intended projects have been introduced. (Bjelic, 2021)

Important milestone when it comes to Serbia´s legislation took place from beginning of the 21st century, since before, renewable energy sources haven't even been considered by the relevant laws. Yet, in 2004, 2011 and 2014, Serbia adopted three new energy laws. RES now haven't only been defined, but also discussed in more detail. By fact, the last one, the **Energy Law from 2014**, transposes the EU Third Energy Package, and remains today one of the critical shapers of renewable energy outlooks. Among other, the law defines objectives of energy policy and their implementation, conditions for secure and quality energy supply and delivery, conditions for construction of new energy facilities, etc. (Paragraf, 2023) Additionally, in 2021, Law on the Use of Renewable Energy Sources entered into force as the second most important pillar for RES in Serbia. Among other, this law states objectives and targets for the utilization of RES, elaborates on integration of RE into the market and special procedures for construction and connection, describes incentive systems for electricity generation from RES, etc. The law has been amended in 2023. (Paragraf, 2023)

Defined by the Law on Use of Renewable Energy Sources and particularly important are the incentives systems defined in the section II, under the name Systems of Incentives for electricity production from renewable sources. The section states that such are implemented in a certain incentive period through the system of market premiums and the system of feed-in tariffs, relating to the price of electricity, the assumption of balance responsibility, the right to priority access to the system and other incentives prescribed by the law. (Paragraf, 2023)

4.1.4. Amendments to the Law on Use of Renewable Energy Sources

Perhaps most directly affecting circumstances are those found in the amendments to the Law on Use of Renewable Energy Sources that took force in April 2023. Several articles were adapted, some deleted. Some of the most important changes in the context of PV technologies include added definition on variable renewable energy sources of energy, which are now defined as *´´primary sources of energy (wind energy, solar energy, etc.) whose energy potential depends on meteorological conditions that are difficult to accurately forecast, as a result of which, when producing electricity from such sources, greater deviations can occur between the produced electricity and the planned electricity production in relation to other energy sources´´* (Paragraf)

Secondly, adaptations of the Article 10, ruling the balancing responsibility, can be seen. The changes have protected the guaranteed supplier, EPS, from the financial risk of taking over balance responsibility for all producers from RES. Now, this law foresees this obligation for EPS, but only in relation to **privileged producers** who entered the incentive system, and for a limited period (Portal, 2023).

Thirdly, changes can be seen in the Article 11, ruling rights of privileged access to transmission, distribution and closed distribution systems. Before changes, the article stipulated that the transmission, distribution, or closed distribution systemoperator must take over electricity produced from renewable sources as a priority,regardless of whether it is in the incentive system, except in the case when the safety ofthe operation of the transmission is threatened (MME, 2021) Amendments, however,stipulate that relevant entities have this obligation, but only for demonstration project power plants whose approved power is less than 400 kW, i.e., for power plants that are connected to the grid after January 1. 2026. and of approved power of less than 200 kW regardless of whether they are in the incentivesystem, except in the case when the operational safety of the transmission or distribution system is threatened. Under demonstration project, law defines a non-commercial projectin renewable energy that develops a new technology, surpassing existing ones and havinginnovative status according to the law regulating innovation activities (Paragraf).

Next, another relevant adaptation is the context of energy storage, spread over multiple articles. From now on, TSO will have the possibility for a delay of connection, if it proves, in a transparent manner, that the balancing of the network may be threatened. Still, producers are also given the option to avoid this, by providing for an adequate energy storage. This amended law stipulates, more precisely, that by including batteries with operating power equivalent to a minimum of 20% of the installed active power of the plant, and a capacity of at least 0.4 MWh per every installed megawatt in their plant, investors may take use of this adaptation (Paragraf). An example would be a battery energy storage system of 20 MW and 40MWh fora plant of 100 MW installed capacity. Furthermore, amendments also include conditions for restriction and postponement of connection to the distribution system (Portal, 2023).

Lastly, the market premium system has been altered in a way that citizens benefit. It will enable investors to compete with each other at auctions to obtain incentives, which ultimately leads to better conditions and higher security for the electricity consumers (Portal, 2023).

4.2. Influence of Existing Structures

It is obvious that the broader the legal/strategic provisions are, the weaker the (direct) apparent influence on PV developments. International bodies and their documents and initiatives certainly push Serbia forward and guide the country in the direction of renewable transition. Rulings on the EU level, including those of the Energy Community, have even stronger effect. Based on the Energy Community´s monitoring process, Serbia has indeed moved forward with the aims the same organization is pushing for, which can be seen on the Table 7. Aims in context of electricity, renewable energy and energy efficiency have visibly grown. According to the Minister of Mining and Energy, by fact, Serbia achieved the goal of gross final energy consumption of 27% which was set for 2020, explaining that the government even has a plan to lift the level close to 40% by 2030 (Todorovic, 2023).

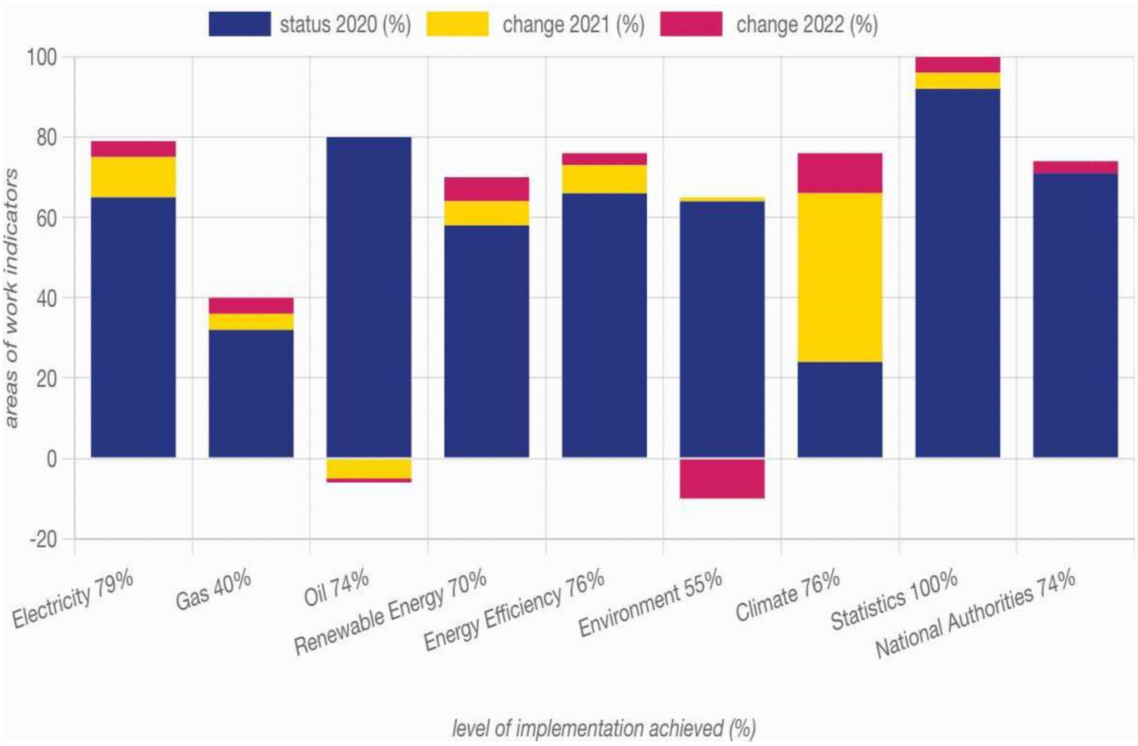

Figure 31: Overall implementation performance of Serbia (EC, Serbia, n.d.).

Referring to the national level context, it is evident that existing rulings have a neutral to positive impact on PV developments in Serbia, considering the increase in grid connection requests discussed in the previous chapter. Regarding the specific amendments to the Law on Use of Renewable Energy, it is clear that by defining variable RES, uncertainties connected to production of electricity through RES begin to be recognized by the law. Furthermore, tightened conditions for balancing responsibility, preferential access, and introduction of necessity for external capacities involved, certainly puts more pressure on investors and producers. From author´s understanding, it is evident that changes aim to protect grid operators and to allow for increasing network security, yet, the question remain, at what cost of future PV expansions. Assumption of the author is that PV expansion remains inevitable, although speed of this trend may be altered.

5. Economic Analysis

In the following section, most important aspects for installment of utility-scale PVPPs in Serbia will be discussed. This includes a stakeholder analysis, discussion of cost and revenues of generating electricity, as well as a consideration of economies of scale by comparing large- and small-scale PV systems.

5.1.Decreasing cost

Important to understand in context of electricity production cots is the notion ot merit-order effect. The effect is namely very widely discussed in the literature, and it follows from the fact that RES marginal costs tend to be closed to zero, and hence an increase in generation shifts the supply curve to the right. As the electricity demand is being inelastic, this results in a fall of electricity prices. What is still not clear is how RES influence the whole distribution of prices. The impacts of this affect on electricity prices is an appealing topic in the literature of electricity markets, and it cen be vizualized by the table bellow (Maciejowska, 2020). Relatively lower wholesale prices of electricity make RES promise consumers lower electricity prices. Whether that will be the case, depends on several other factors.

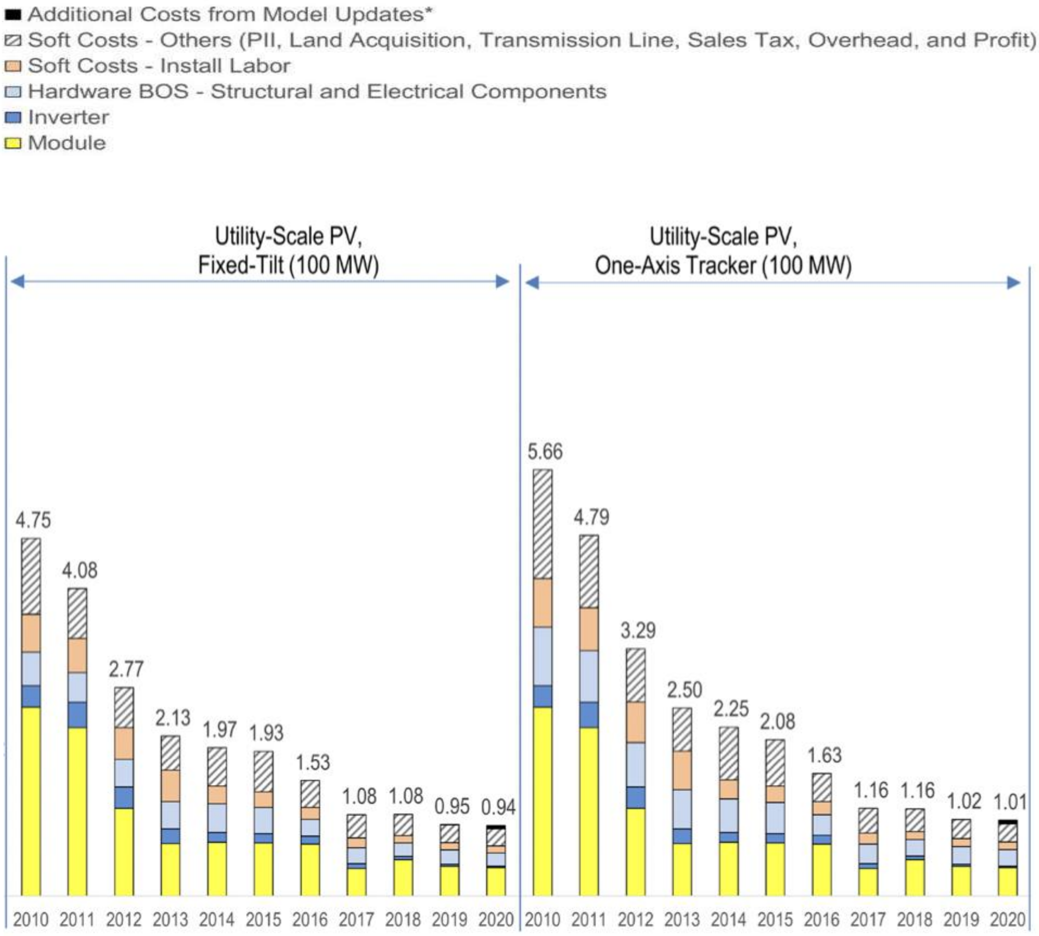

Figure 32: Cost decline of utility-scale PV (Feldman, 2021).

As seen in the Figure 14, in the last decade we have witnessed a sharp continous decline in costs, largly driven by PV module efficiencies and hardware and inverter costs. Since 2010, decreases of 64%, 69%, and 82% in the cost of residential, commercial-rooftop, and utility-scale PV systems, respectively, have been captured. Soft costs remain with a large and persistent percentage of installation costs (Feldman, 2021).

5.2. Revenue determinates

Unfortunately, higher integration of RES with today´s grid infrastructures commonly comes with difficulties. Electricity generated by solar is intermittent and difficult to forecast, being strongly dependent on weather conditions. Because of this, it becomes more challenging to balance the market, especially without appropriate energy storage technologies. It is thereby interesting to look at retail prices as well, together with mechanisms are to mitigate fluctuation risk for producers.

5.2.1. Prices

Retail electricity prices have not seen the same decreases as wholesale electricity prices. They can be influenced by several factors, such as the fluctations of fossil fuel prices and renewable energy costs, choice of technologies in the specific supply mix, capital expenditures per technology, market conditions in general, etc. (Oosthuizen, 2022). Studies confirmed the a priori theoretical assumption of a positive correlation of the share of renewable energy and retail prices. Namely, an increase (decrease) in this share will ultimately lead to an increase (decrease) of retail electricity prices. However, IRENA projected that RES would be price competitive with fossil fuels by 2024, and that eventually, the relationship will show up as negative. It is important to also note that these relations vary across different market structures, from monopolized to competitive ones (Oosthuizen, 2022). The correlation can be seen in the figure below.

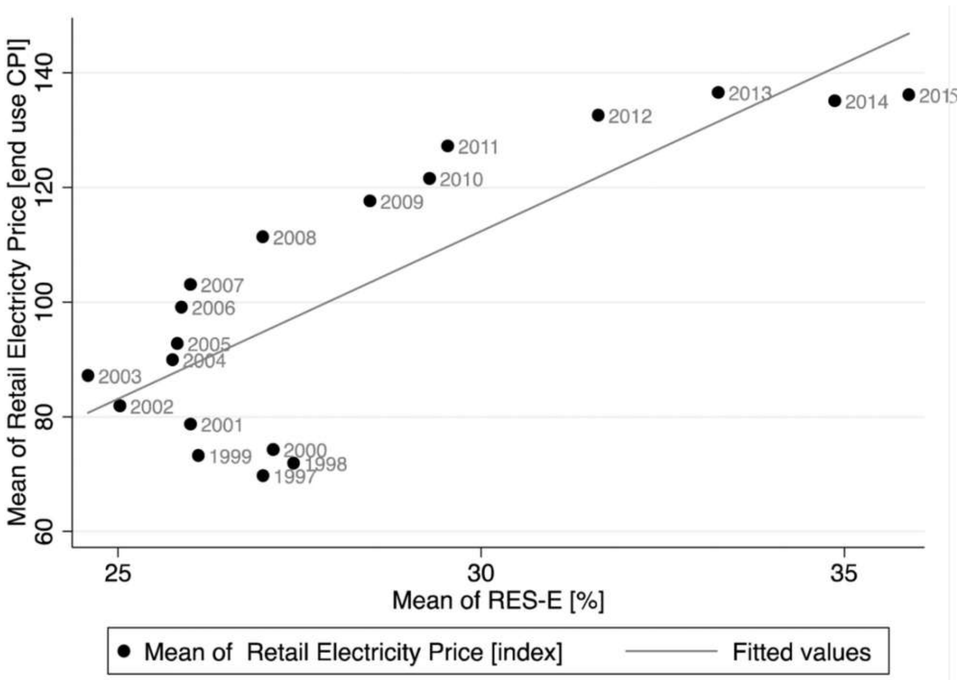

Figure 33: Prices (Oosthuizen, 2022).

Interesting in the context ist to take a look at the increase of average electricity base price in Serbia from 2020 to 2021. The average base price in 2021 was 114.02 €/MWh, and thereby 192.36% higher than in 2020. (SEEPEX, 2021) Graph is obtained from SEEPEX, national power utility company of Serbia.

Figure 34: Trading volume 2020/2021 in Serbia (SEEPEX, 2021).

5.3.2 Mechanisms

Relevant mechanism for determination of electricity prices is the feed-in tariff system. Serbian law defines it as a type of operational state aid that is granted as an incentive purchase price guaranteed per kWh of electricity supplied to the power system during an incentive period. They are calculated and paid on a monthly base, and can be received for all or parts of the power plant's capacity. The are assigned in the process of auctions, and based on the available quotas given by the Government, which also determines the maximum feed-in tariff that could be given. However, important to note, is that feed-in tariffs are acquired only for small plants and demonstration projects (Paragraf). The system in Serbia has been first introduced in 2013, with aim to stimpulate production of electricity from RES. Partially, its up to consumers to take the burden. Fort the approximation, its interesting to know that in 2016 EPS received RSD 2,5 million for its renewable electricity. By fact, consumers pay RSD 0,801 for every kWh, meaning that a monthly consumption of 700 kWh accounts to around EUR 5 from consumers pockets in the regime of feed-in tariffs (Energologija, 2023)

According to the Law on Use of Renewable Energy, market premium is another type of operational state aid but in form of an addition to the market price of electricity that users of the market premium deliver to the market, and is being determined in eurocents per kWh during the auction process. Same as a feed-in tariff, it can be acquired for all or parts of the power plant's capacity. It is also paid on a monthly basis. for the electricity supplied by the power plant to the power system. Furthermore, it is again the Government that determines the maximum offered price for electricity per MWh (Paragraf). Unlike, those who are entitled to a feed-in tariff, producers of larger power plants will sell their electricity on the free market to whoever they want, and they will always have the price they won, regardless of the stock market price (Energologija, 2023). Market premium system therefore seems more transparent and market-oriented, as the market price of electricity is part of the total income privileged producers get.

6. Social Analysis

The following chapter focuses on social aspects that have a role in shaping the future of PV expansions in Serbia. Firstly, societal, and environmental considerations will be presented. Topics of climate change activism and air pollution in Serbia will be discussed, as relevant determinates of public opinion on RES in Serbia. Next, geopolitical implications will be considered, including three concepts, namely the outbreak of Covid19, warfare in Europe, and Serbo-Chinese relations. From author´s point of view, all these aspects appear as beneficial conditions for future PV developments in Serbia. Arguments will be provided by the end of each paragraph.

6.1. Societal and Environmental Factors

Climate change concerns long-term changes in temperatures and weather patterns that have since centuries been caused by natural events. From the 1800s, human activities started having immense effects on the climate, primarily through the effects of burning of fossil fuels like coal, oil, and gas. These combustion processes generated GHG (mainly carbon dioxide and methane) that trap sun´s heat, leading to ever-rising temperatures. Among main sectors that cause greenhouse gases is also the energy sector. It is well known that potential consequences can be mitigated, and main pillars of the process include usage of renewables and dismissal of conventional energy fuels. (United Nations, n.d.)

Over the past two decades, Serbia experienced severe droughts, floods, harshwinters, and other weather-related extreme events that imposed immense physical damage, financial losses and even death cases, most significantly affecting Serbia´seconomy, with focus on agriculture. Projections imply that this region carries a high probability of more frequent and prolonged droughts and wildfires (World Bank, 2021) Thankfully, intensifications of climate change brought about increases in climate change activism, which in various forms, targets entities of power – policymakers, regulators, and businesses to react promptly. It encompasses demonstrations, educational campaign, online activism, climate litigations, and many more. From author´s experience, it is highly evident that global activism created a ripple effect, influencing public opinion in Serbia. People became more aware of the environmental consequences and benefits of the RES, so a shift in societal attitudes towards supporting such energy systems can be observed. This thereby includes PV technologies as well.

Another important aspect of the awakening process for the urgency of RES employment is the specific context of air pollution in Serbia, and internal demonstrations and movements that arise. By fact, Serbia is home to some of the most polluting coal plants in Europe, and today considered 5th most polluted country in Europe when it comes to levels of air pollution (IQAir, n.d.). Talking from experience, winters in Serbia tend to really get unbearable, with smog covering streets and decreasing visibility. Science confirms that PM particles harm humans most forcefully, causing respiratory issues, damaging cardiovascular health, leading to allergies and irritations in humans, etc. In general terms, quality of life indeed gets significantly reduced, as daily activities become limited – people cannot go for a longer walk and cannot think of doing sports outside. What is worst, is that such level of air pollution not only limits outdoor activities, but also lives. WHO data show that pollutants as PM and SO2 lead to premature deaths in Serbia, in various cases (WHO, 2019). ´´Kreni promeni´´, ´´Ne davimo Beograd´´ and ´´Cist vazduh´´are only some of the movements created throughout the course of this ´´air crisis´´, as some tend to call it. These persistently high levels of air pollution in Serbia have indeed installed a sense of fear among the citizens, confirming even more strongly the support RES (and PV) expansions would, on a general level, have.

6.2. Geoplolitical Implications

While the outbreak of Covid19 dates from the end of 2019, economies and people are still recovering from the devastating events and experience. Although life-patterns tend to sporadically change over time, crisis that emerged in 2019 took a rapid turn in changing people´s lives, habits and spending patterns, at the speed and scale the world has never seen. Some argue that in such scenario, a strong base in cluster of innovative technologies is inevitable, and that economic disruptions indeed tend to facilitate changes and stronger creativity. As the global energy sector represents one of the crucial pillars of modern society, it is understandable that it has been influenced most considerably. Various articles point to the fact that humanity started experiencing a new wave of innovation driven by renewable energy sector combined with smart-city technology (Klemes, 2021) Representation of wave-innovation can be seen in the picture bellow.

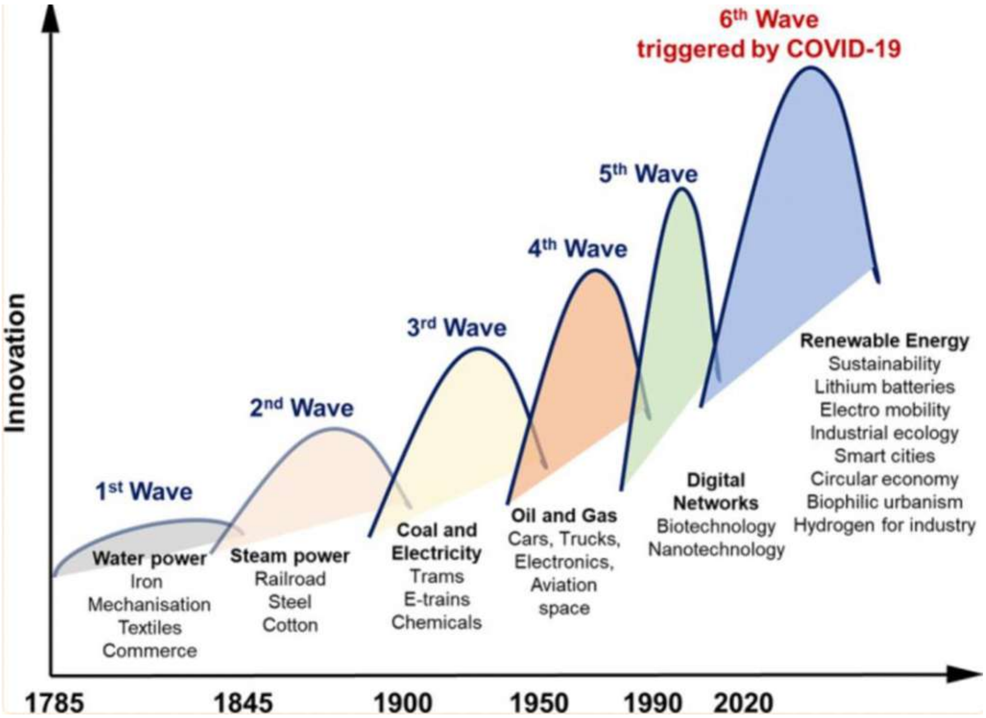

Figure 35: Waves of innovation through industrial history into the future (Klemes, 2021)

From author´s understanding, it is undeniable that the pandemic acted as a catalyst for technological innovation in energy sector. Vulnerabilities of conventional energy systems and traditional supply chains have been exposed, and growing research pointed to the need for resilient and sustainable energy sources. It is reasonable to understand why governments and businesses increasingly turned their attention to the RES. It is RES´ agility and adaptability that allowed for developments, while other energy sources experienced declines. Although what we are talking about now are mere consequences, with the understanding of background of the RES emergence, one can understand this phenomenon as a trend that is here to stay – decisively opening doors for future expansionsin PV and other spheres.

Although Covid19 to some extent also pointed onto the need of energy security, new escalations on the world scale made circumstances quite clear. Appearing as sadly not the only armed conflict of the 21st century, the escalated Russo-Ukrainian war took the global scene in 2022. The world has witnessed unprecedented devastation of cities, infrastructure, taking the lives of many. This global context significantly disrupted the global economy and energy markets, roiling global prices and supply chains. From experience learned and lessons taken after the sanctions against Russia, it's getting urgent for European countries to find ways to reduce their dependance on Russian energy, ana formulate strategies that would ensure energy security, stability, and development. Being abundant and, in some sense, available to all, green energies offer a potential solution on the wide base, allowing countries to adjust their strategic layouts based on their natural capabilities. This opens door for wave of anti-globalization and emergence of semi-autonomous regional blocks with decentralized value chains. Furthermore, it could also mean rising trends of nation-state policies and ´´re-shoring´´ (Cui, 2023). In this context it is also important to consider Serbia´s particular geopolitical context, as the country, unlike most of the Europe, has specific (diplomatic) ties with Russia, having as base historical legacies and a sense of camaraderie among their people. In any case, ongoing wars and mistrust that is being built worldwidevhave affinity to bring upfront RES (and PV) technologies in Europe, including Serbia.

Historically, Serbia´s destiny has destiny has predominately been shaped by geography and its central position in Europe and world. Some like to say that the country is looking East but going West. In this context, another aspect of relevance is Serbia´s relation to the People´s Republic of China. Geostrategically, Serbia is of great importance to China. China´s presence in Serbia can be viewed from two dimensions, namely from the aspect of foreign trade and in the form of foreign investment. On the one hand, Serbia presents an important strategic link and transit area between the Chinese and European markets.

On the other, Serbia´s need for foreign capital, favorable conditions granted to investors and availability of resources and cheap skilled labor create beneficial base for Chinese investments. Changing the perspective to side of Serbia, advantages are again evident, showing both economic and political advantages that arise due to cooperation with this emerging global player. Firstly, China provides support to Serbia in preserving sovereignty and territorial integrity, especially through its role as permanent member to the UN Security Council (Božić-Miljković, 2021). Moreover, particularities of the new world order emerging with the Russo-Ukrainian war are yet to be seen, with projections pointing into increased Russo-Chinese cooperation, possibly altering Serbia´s global position even further (Cui, 2023). Next, presence of Chinese companies for Serbia indicates an increase in production and exports, and reduction in unemployment, boosting country´s national economy and growth. Understanding the depth of this relation, one can now see advantages for the RES and PV sector (Božić-Miljković, 2021). China is seen as the global leader in PV manufacturing, installations, and development. In 2022, the country brought into opeartion 87.41 GW of new solar power, increasing total installed capacity to 392.61 GW (Yu C. , 2023). Reading about numerous Chinese companies showing interest in Serbia´s PV industry, some of them being Power China, Shanghai Electric Group and China Machinery Engineering Corporation, it is evident that China represents an important factor, positively affecting photovoltaic expansion in Serbia.

7. Cost Benefit Analysis: Kolubara A

In line with energy transition, world has started to see abandoning of unsustainable power plants. On these areas, more particularly at ash and slag dumps, construction of solar power plants has become a practice. This not only accelerates energytransition, but it also implies decarbonization and development of renewables. This started being the case in Serbia as well. EPS, owning and operating coal mines and thermal plants, seeks to harmonize and align its strategic investments and operations with the regulations mentioned in the previous chapter. To enrichen the results of the thesis, author has chosen to include a CBA for one of the planned projects of this public enterprise, the Kolubara A PVPP project. This way, analysis can be supported by calculations from a real-life project, showing viability in most practical sense. This chapter will therefore include introduction to this particular project, thereby briefly explaining necessary project implementation steps. Next, results will be presented together with discussion.

7.1. Project Information

Thermal Power Plant Kolubara A is an existing power plant belonging to the state-owned electricity utility Public Enterprise Elektroprivreda Srbije – PE EPS. It encompasses a block of 239 MW installed capacity and represents one of the oldest but relatively smaller thermal power plants in the ownership of EPS. It is located on the area of Veliki Crljeni settlement close to town of Lazarevac. It has been in operation since 1956, using lignite from open pit mine Kolubara, and participating with a share of 2% in the total national electricity generation. In the year of 2021, it produced 681 GWh of electricity, yet, emitting 22.411 tonnes of SO2, 2.104 tonnes of NOx, around 1 mill. tonnes of CO2 and 2.615 tonnes of PM particles.

After noting that the power plant doesn't comply with ecological requirements of the EU´s Large Combustion Plants Directive, it has been decided that plant must be withdrawn from production with the existing technology until 2024, with possibility that it is made available for the application of new (renewable) ones. EPS announced a tender for two envisaged projects, namely, they called for the terrain analysis of Kolubara A coal power plants, with intention to create a solar power plant on relevant area. Same was planned for the Morava coal power plant as well. In both cases, a preliminary feasibility study was necessary for the possible construction (Spasic, 2021).

In December 2022, Balkan Green Energy News confirmed that EPS received an official confirmation that funds they have requested under 28th call for technical assistance and the 7th call for co-financing investments have been confirmed. Namely, the state enterprise was said two receive two grants, EUR 860.000 each, for the two solar projects at old Kolubara and Morava thermal power plants. These funds are part of the EU´s EUR 49,02 million aid package through the Western Balkans Investment Framework. Within Kolubara A, the solar power plant will be built on a coal storage site and an ash landfill, and envisaged capacity marks 71 MW, and an annual production of 96 GWh. Total investment is estimated at EUR 80.14 million, with EBRD being the leading potential creditor (2022) This was undoubtedly a success for Serbia, receiving multiple grants from side of one applicant. According to interview data, the project is expected tohave a start date in September 2023, and is planned to be finished by end of 2026.

A project as such is expected to create many benefits for Serbia. It will provide for a modern ecological recovery, by means of rehabilitation of the wasteland created in the second half of 20th century. Also, amount of wastewater that would in another context be used for the transport of ash will be reduced. Next, the project would support sustainable development of the local community (municipality of Lazarevac), and would create more jobs – temporary, but also permanent, for operation and maintenance. Furthermore, it would lead to a decrease in air pollution, canceling emissions of CO2, NOx and PM that arise from combustion processes. Being in line with national strategies and policies, and supporting the EU initiatives and the Paris Agreement, it will also support national efforts in increasing the participation of the RES in total electricity production and will contribute to global aims of decarbonization. In the context of finances, the project is recognized as an alternative land use, ultimately reducing potential liabilities for land rehabilitation, and presenting a financial benefit from the project. The project without a doubt presents a stream of advantages for Serbia. Yet, whether its whole implementation will altogether be financially viable, and if yes, to what extent, is another question.

7.2. Results and Discussions

As well known, Cost Benefit Analysis is a helpful tool when assessing attractivity of project. It sums the potential (monetary) rewards expected from an action, in this case project, and then subtracts the total costs associated with that action/project. For the scope of this analysis, several financial metrics have been used, and relevant results will be presented below. Important to know are the assumptions and data taken as input. The author takes corporate tax rate of 15% and considers that the plant is put into operation in September 2026, having thereby only 3 full active months in the first year. Electricity feed in price of 10 c/kWh is taken and energy yield is approximated to 1200 kWh/kWa. EPC price of 0.8 € /Wp. Furthermore, depreciation time of 20 years has been used. Total financing is approximated to EUR 56,8 million, with operation and maintenance costs being 1% of the amount, and reserves for replacements being 1,5% of the same amount. The total amount is being financed by 30% over equity, and loans are being repaid for 15 years, with an interest of 4%.

Table 4: Cash Flow Analysis

Cash Flow						
Commissioning year		**1**	**2**	**3**	**4**	**5**
Calender Year		2026	2027	2028	2029	2030
Production	kWh	21.023.739	83.842.671	83.591.143	83.340.370	83.090.349
Specific Income	c€/kWh	10,00	10,00	10,00	10,00	10,00
Revenue	**€**	**2.102.374**	**8.384.267**	**8.359.114**	**8.334.037**	**8.309.035**
Operational Expences						
Rent	€	168.980	168.980	168.980	168.980	168.980
Operation and Maintenance	€	140.000	571.200	582.624	594.276	606.162
Reserves for Replacements	€	210.000	840.000	840.000	840.000	840.000
Investments						
PV Investment	€	56.800.000				
Land/Roof Investment	€	0				
Financing						
Investment Subsidy	€					
Cash Flow before Tax	**€**	**-55.216.606**	**6.804.087**	**6.767.510**	**6.730.780**	**6.693.893**
Tax	€	0	167.562	589.127	583.617	578.084
Cash Flow After Tax	**€**	**-55.216.606**	**6.636.525**	**6.178.384**	**6.147.163**	**6.115.809**
IRR unlevered	9,7%					

the course of the Cash Flow Analysis, inflows and outflows of cash for the period of 40 years have been calculated, with first 5 years presented in table above. One can see that after the initial investment of around EUR 55 million in the first year, the plant´s cash inflows start surpassing the outflows in 2027, mainly due to higher revenues. An unlevered IRR of 9,7% has been reached, noting that the project is expected to generate a return of 9.7% on the invested capital over its lifespan. Important to note that the analysis is unlevered, meaning financing costs have been disregarded for this part.

Table 5: Profit and Loss statement

Commissioning year		1	2	3	4	5
Calendar Year		2026	2027	2028	2029	2030
Production	kWh	21.023.739	83.842.671	83.591.143	83.340.370	83.090.349
Tariff	c€/kWh	10,00	10,00	10,00	10,00	10,00
Revenues	**€**	**2.102.374**	**8.384.267**	**8.359.114**	**8.334.037**	**8.309.035**
Land lease	€	168.980	168.980	168.980	168.980	168.980
OPEX	€	140.000	571.200	582.624	594.276	606.162
Reserves	€	210.000	840.000	840.000	840.000	840.000
Incentives	€					
EBITDA	**€**	**1.583.394**	**6.804.087**	**6.767.510**	**6.730.780**	**6.693.893**
Depreciation plant	€	2.840.000	2.840.000	2.840.000	2.840.000	2.840.000
Depreciation othersplant	€					
EBIT	**€**	**-1.256.606**	**3.964.087**	**3.927.510**	**3.890.780**	**3.853.893**
Interests	€	1.590.400	1.510.974	1.428.370	1.342.463	1.253.119
EBT	**€**	**-2.847.006**	**2.453.113**	**2.499.140**	**2.548.318**	**2.600.774**
Loss carried forward	€		-2.847.006	-393.893		
Taxable profit	€	-2.847.006	-393.893	2.105.247	2.548.318	2.600.774
Corporate tax	€	0	0	315.787	382.248	390.116
NOPLAT	**€**	**-2.847.006**	**2.453.113**	**2.183.353**	**2.166.070**	**2.210.658**
DSCR		0,44	1,90	1,80	1,78	1,76
DSCR average over loan period		1,64				
IRR unlevered		9,7%				

On the other hand, profit and loss analysis deals with revenues, expenses and net profit or loss of the project. This analysis has also been calculated for the scope of 40 years, with first 5 being presented in the Table 10. In this context, investment costs have been considered within appropriate expense categories. Due to fewer months of operation in the first year, 2026 achieved a loss, unlike the following years. Additionally, am average over loan period debt service coverage ratio of 1.64 has been achieved, indicating a relatively healthy level of cash flow to cover the debt.

Table 6: Results Summary

WACC:	4%
Years:	25
Comment	
Cash Flow Before Tax Results	
Total CF 25 years	80.164.564 €
Discounted CF 25 years	41.597.391 €
IRR 25 years (30% Equity)	16,9%
Cash Flow After Tax Results	
Total CF 25 years	67.603.471 €
Discounted CF 25 years	34.151.810 €
IRR 25 years (30% Equity)	15,0%
Profit and Loss Results	
Total Profit 25 years	76.171.797 €
Discounted Profit 25 years	42.086.169 €

Table 10 summarizes the main results, and discounts the achieved values, meaning, expresses them in terms of today´s value.

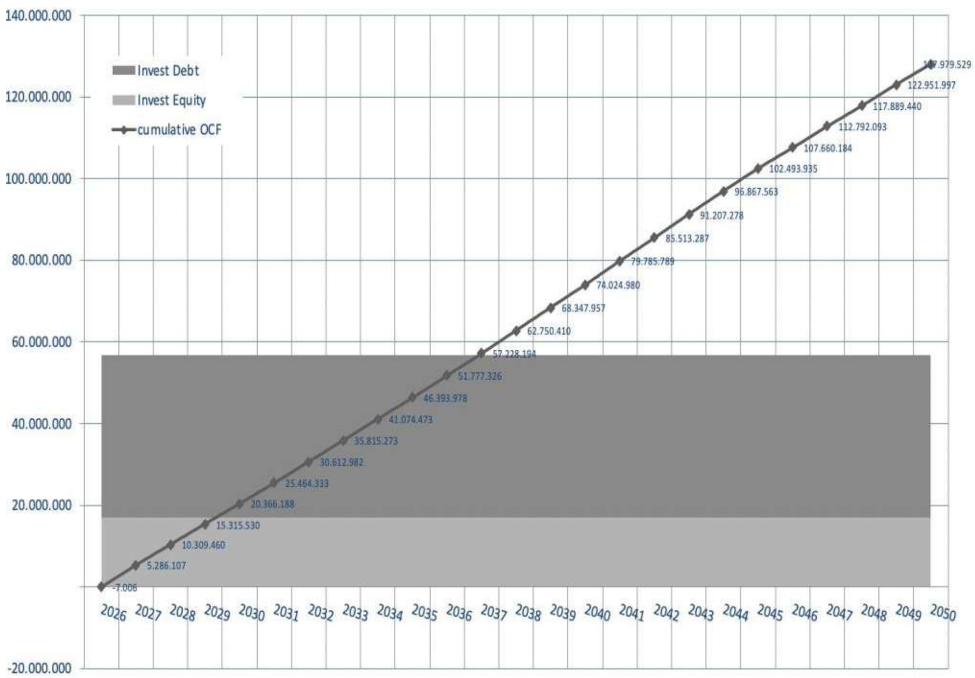

Figure 36: Cumulative operative cash flow

Figure 18. shows development of cumulative operative cash flow. It is visible that by the end of 2036, total cash generated from the project´s core operations will surpass total cash consumed by the same operations.

UNLEVELED IRR — Land costs in EUR / MW-AC

PV plant costs incl. Substation and grid connection fee in EUR/Wp (10%)	2000	2200	2300	2400	2500	2600	2700	2800	2900	3000	
0,7	11,6%	11,5%	11,5%	11,5%	11,5%	11,5%	11,5%	11,5%	11,4%	11,4%	>12%
0,72	11,2%	11,1%	11,1%	11,1%	11,1%	11,1%	11,1%	11,1%	11,1%	11,0%	10-12%
0,74	10,8%	10,8%	10,8%	10,7%	10,7%	10,7%	10,7%	10,7%	10,7%	10,7%	<10%
0,76	10,4%	10,4%	10,4%	10,4%	10,4%	10,4%	10,3%	10,3%	10,3%	10,3%	
0,78	10,1%	10,1%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	
0,8	9,8%	9,7%	9,7%	9,7%	9,7%	9,7%	9,7%	9,7%	9,6%	9,6%	
0,82	9,4%	9,4%	9,4%	9,4%	9,4%	9,4%	9,3%	9,3%	9,3%	9,3%	
0,84	9,1%	9,1%	9,1%	9,1%	9,1%	9,1%	9,0%	9,0%	9,0%	9,0%	
0,86	8,8%	8,8%	8,8%	8,8%	8,8%	8,8%	8,8%	8,7%	8,7%	8,7%	
0,88	8,6%	8,5%	8,5%	8,5%	8,5%	8,5%	8,5%	8,5%	8,4%	8,4%	
0,9	8,3%	8,3%	8,2%	8,2%	8,2%	8,2%	8,2%	8,2%	8,2%	8,2%	
0,92	8,0%	8,0%	8,0%	8,0%	8,0%	8,0%	7,9%	7,9%	7,9%	7,9%	
0,94	7,8%	7,7%	7,7%	7,7%	7,7%	7,7%	7,7%	7,7%	7,7%	7,7%	
0,96	7,5%	7,5%	7,5%	7,5%	7,5%	7,5%	7,5%	7,4%	7,4%	7,4%	

DSCR — Equity share

PV plant costs incl. Substation and grid connection fee in EUR/Wp (164%)	5,0%	10,0%	15,0%	20,0%	25,0%	30,0%	35,0%	40,0%	45,0%	50,0%	
0,7	137,4%	144,8%	153,1%	162,4%	173,0%	185,0%	199,0%	215,2%	234,4%	257,5%	>130%
0,72	133,9%	141,1%	149,2%	158,3%	168,6%	180,3%	193,9%	209,7%	228,5%	250,9%	100%-130%
0,74	130,6%	137,7%	145,5%	154,4%	164,4%	175,9%	189,1%	204,6%	222,8%	244,7%	<100%
0,76	127,5%	134,4%	142,1%	150,7%	160,5%	171,7%	184,6%	199,6%	217,4%	238,8%	
0,78	124,6%	131,3%	138,8%	147,2%	156,8%	167,7%	180,3%	195,0%	212,3%	233,2%	
0,8	121,8%	128,3%	135,6%	143,9%	153,2%	163,9%	176,2%	190,5%	207,5%	227,9%	
0,82	119,1%	125,5%	132,7%	140,7%	149,8%	160,3%	172,3%	186,3%	202,9%	222,8%	
0,84	116,6%	122,8%	129,8%	137,7%	146,6%	156,8%	168,6%	182,3%	198,5%	218,0%	
0,86	114,2%	120,3%	127,1%	134,8%	143,6%	153,5%	165,1%	178,5%	194,4%	213,4%	
0,88	111,9%	117,9%	124,6%	132,1%	140,6%	150,4%	161,7%	174,8%	190,4%	209,0%	
0,9	109,7%	115,5%	122,1%	129,5%	137,9%	147,4%	158,5%	171,3%	186,6%	204,8%	
0,92	107,5%	113,3%	119,7%	127,0%	135,2%	144,6%	155,4%	168,0%	182,9%	200,8%	
0,94	105,5%	111,2%	117,5%	124,6%	132,6%	141,8%	152,4%	164,8%	179,4%	197,0%	
0,96	103,6%	109,1%	115,3%	122,3%	130,2%	139,2%	149,6%	161,8%	176,1%	193,3%	

DSCR — Interest rate loan

PV plant costs incl. Substation and grid connection fee in EUR/Wp (164%)	2%	2,5%	3,0%	3,5%	4,0%	4,5%	5,0%	5,5%	6,0%	6,5%	
0,7	211,5%	204,3%	197,6%	191,1%	185,0%	179,2%	173,7%	168,5%	163,5%	158,8%	>130%
0,72	206,1%	199,1%	192,5%	186,3%	180,3%	174,7%	169,3%	164,3%	159,4%	154,8%	100%-130%
0,74	200,9%	194,2%	187,7%	181,7%	175,9%	170,4%	165,2%	160,2%	155,5%	151,1%	<100%
0,76	196,1%	189,5%	183,2%	177,3%	171,7%	166,3%	161,3%	156,4%	151,9%	147,5%	
0,78	191,4%	185,0%	178,9%	173,2%	167,7%	162,5%	157,5%	152,8%	148,4%	144,1%	
0,8	187,1%	180,8%	174,9%	169,2%	163,9%	158,8%	154,0%	149,4%	145,0%	140,9%	
0,82	182,9%	176,8%	171,0%	165,5%	160,3%	155,3%	150,6%	146,1%	141,9%	137,9%	
0,84	178,9%	172,9%	167,3%	161,9%	156,8%	152,0%	147,4%	143,0%	138,9%	134,9%	
0,86	175,1%	169,3%	163,8%	158,5%	153,5%	148,8%	144,3%	140,1%	136,0%	132,2%	
0,88	171,5%	165,8%	160,4%	155,3%	150,4%	145,8%	141,4%	137,3%	133,3%	129,5%	
0,9	168,0%	162,5%	157,2%	152,2%	147,4%	142,9%	138,6%	134,6%	130,7%	127,0%	
0,92	164,7%	159,3%	154,1%	149,2%	144,6%	140,1%	136,0%	132,0%	128,2%	124,6%	
0,94	161,6%	156,2%	151,2%	146,4%	141,8%	137,5%	133,4%	129,5%	125,8%	122,3%	
0,96	158,5%	153,3%	148,4%	143,7%	139,2%	135,0%	130,9%	127,1%	123,5%	120,0%	

UNLEVELED IRR — Interest rate loan

PV plant costs incl. Substation and grid connection fee in EUR/Wp (0,10)	7	7,50	8,00	8,50	9,00	9,50	10,00	10,50	11,00	11,50	
0,7	5,7%	6,7%	7,7%	8,7%	9,6%	10,6%	11,5%	12,4%	13,2%	14,1%	>12%
0,72	5,4%	6,4%	7,4%	8,4%	9,3%	10,2%	11,1%	11,9%	12,8%	13,6%	10-12%
0,74	5,1%	6,1%	7,1%	8,0%	8,9%	9,8%	10,7%	11,5%	12,4%	13,2%	<10%
0,76	4,9%	5,9%	6,8%	7,7%	8,6%	9,5%	10,3%	11,2%	12,0%	12,8%	
0,78	4,6%	5,6%	6,5%	7,4%	8,3%	9,1%	10,0%	10,8%	11,6%	12,4%	
0,8	4,4%	5,3%	6,2%	7,1%	8,0%	8,8%	9,7%	10,5%	11,2%	12,0%	
0,82	4,1%	5,1%	6,0%	6,9%	7,7%	8,5%	9,3%	10,1%	10,9%	11,7%	
0,84	3,9%	4,8%	5,7%	6,6%	7,4%	8,2%	9,0%	9,8%	10,6%	11,3%	
0,86	3,7%	4,6%	5,5%	6,3%	7,2%	8,0%	8,7%	9,5%	10,3%	11,0%	
0,88	3,5%	4,4%	5,3%	6,1%	6,9%	7,7%	8,5%	9,2%	10,0%	10,7%	
0,9	3,3%	4,2%	5,0%	5,9%	6,7%	7,4%	8,2%	8,9%	9,7%	10,4%	
0,92	3,1%	4,0%	4,8%	5,6%	6,4%	7,2%	7,9%	8,7%	9,4%	10,1%	
0,94	2,9%	3,8%	4,6%	5,4%	6,2%	6,9%	7,7%	8,4%	9,1%	9,8%	
0,96	2,7%	3,6%	4,4%	5,2%	6,0%	6,7%	7,4%	8,2%	8,8%	9,5%	

Figure 37: Sensitivity Analysis

Table 12. shows the results of the sensitivity analysis, visualizing how changes in certain variables affect certain resulting outcomes of the project.

Conclusion

The aim of this thesis was to evaluate potential and viability of utility-scale PV power plants in Serbia. The essence ultimately reflects preparedness of Serbia for the ongoing, aiming (energy) transition. The research focused on the technological, technical, legal, strategic, economic and social aspects, for the Republic of Serbia. It has resulted into following takeaways.

Firstly, photovoltaic (PV) power plants could be developed in Serbia with a lot more potential than the country currently needs in terms of electricity, with the technical conditions Serbia is offering. The infrastructure of the current system is capable of handling the rising generation of power, but additional upgrades are required to guarantee supply security and dependability. Furthermore, Serbia´s lithium reserves will play a significant role in shaping further events, especially in the context of batteries as energy storage.

Secondly, it is visible that the broader the legal/strategic provisions are, the weaker the (direct) apparent influence on PV developments is. International bodies and their documents and initiatives indeed push Serbia forward and guide its way on the path of sustainable transition. More apparent effects are achieved at the EU level, especially around the work of Energy Community, that successfully manages relevant regions. Yet, affects of national frameworks ultimately shape the outlook. It is evident that new amendments to the Law on Energy Use will lead to higher protection and security of the gird, yet, it is expected that they bring in higher cost for electricity producers.

Thirdly, trends of decreasing cost and increasing retail electricity prices are evident, making conditions monetary favorable for the investors and project developers. Expectations exist that prices from RES will soon be price competitive with ones from fossil-fuel sources. Although altered with amendments to the National Law, mechanisms still play a crucial role for security of producers and developers.

Societal and environmental trends have created a solid base for intensification of need for RES, both globally, and in Serbia, especially due to high levels of pollution in the last couple of years. Considered geopolitical implications of Covid19 and ongoing global warfare pave the way of RES expansion even further, pushing countries in the direction of energy independency, and technological innovation. Specific ties with China represent a crucial factor for Serbia´s future PV developments.

Based on takeaways, it can be assumed that Serbia has a positive outlook in context of utility scale PVPP expansions, when considering potential and viability. Furthermore, it has been shown that Kolubara A measures a discounted cash flow of 25 years, when considering 25 year period, showing that the project will generate more cash over the period than the initial investment.

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