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Towards a Sustainable Energy Future in Kosovo – Balancing Development, Environmental Concerns and Renewable Solutions

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ABSTRACT

This paper focuses on the multifaceted exploration of energy transition strategies in Kosovo, with a particular emphasis on the potential for repurposing degraded lands for renewable energy generation. As a developing nation grappling with increasing electricity demand and environmental concerns, Kosovo seeks to reconcile economic growth with ecological sustainability. The study examined the use of solar photovoltaic (PV) systems as a viable renewable energy source, utilizing Kosovo's abundant sunshine and strategic location. The research identifies the Sibovc coal basin as a focal point, analyzing its potential for transitioning toward cleaner energy alternatives. By examining six potential areas, the study proposed implementing a pilot project within an 80 ha parcel, with prospects for future expansion. Importantly, the investigation underscores the significance of integrating degraded lands resulting from past mining activities into renewable energy infrastructure, thereby mitigating pollution and fostering sustainable development. Simulation results, obtained using PVsyst and RETScreen to evaluate the feasibility and environmental impact of solar PV installations, indicated promising outcomes. Projections suggest a substantial reduction in CO_2 emissions through the establishment of PV solar parks. Furthermore, the research highlighted the growing demand for renewable energy solutions driven by advancements in technology and cost-effectiveness, emphasizing the potential of installing solar panels on degraded surfaces as a sustainable alternative. Through innovative approaches and strategic utilization of available resources, Kosovo strives to align with global sustainability goals and contribute to the broader discourse on climate action and energy transition.

Keywords: electricity, environmental, renewable energy, solar photovoltaic systems.

INTRODUCTION

Recognizing the crucial role electricity plays in facilitating human activities, fostering economic growth, and advancing societal welfare, we are confronted with the reality that constructing a solar panel center demands considerable space, a resource not readily available in Kosovo. Electricity plays a pivotal role in facilitating human activities, fostering economic growth, and advancing societal welfare. However, its environmental ramifications, particularly concerning global warming, present significant challenges to contemporary society. Within the context of Kosovo's status as a developing nation, there exists a continual surge in electricity demand, thereby eliciting diverse environmental repercussions, both on a local and regional scale. The primary objective entails mitigating pollution levels while concurrently propelling economic progress through the adoption of clean energy technologies. The overarching goal is to attain a state of carbon neutrality,

thereby upholding environmental standards and fostering ecological sustainability.

The global statistics show that the investments in sustainable and cleaner energy sources have accelerated in recent decades due to concerns about climate change, air pollution, and the depletion of fossil fuel reserves (IEA, 2024; Eurostat. 2023; Statistical, 2023; Climatescope, 2023; IEA, 2023). In Kosovo, coal is currently a vital source of electricity production, accounting for over 94% of it, offering a relatively affordable option for local consumers (ERO, 2023). However, Kosovo is not a signatory to the Paris Agreement (The Paris Agreement, 2015), but through other regional initiatives, it has committed to gradually phasing out coal-fired power plants and replacing them with renewable energy sources.

One potential renewable source, due to the abundant sunny days, is the solar PV system, where the solar radiation in Kosovo is estimated to be between 1300 and 1500 kWh/m^2 per year (Hydrometeorological, 2023). With approximately 278 sunny days, Kosovo can be considered a country that has clear predispositions for the use of this resource (Photovoltaic. 2023), but it requires large land areas for solar photovoltaic system (SPS) installation (Maharshi et al., 2022).

Kosovo, situated in the center of the Balkans, is a landlocked region bordered by Albania to the southwest, North Macedonia to the southeast, Montenegro to the west, and Serbia to the north and east. Approximately 10 km west of capital Pristina lies one of the largest lignite mines, owned and operated by Kosovo Energy Corporation (KEK). Presently, the sole actively exploited coal basin is the Sibovc mine, serving as the northwest extension of the two previously depleted mines, Bardh and Mirash. These depleted mines are currently repurposed as overburden dump deposits.

The aggregate operating capacity for electricity generation in Kosovo is 1,236 MW, with thermal power plants contributing 960 MW, constituting 77.7% of the total capacity. The remaining capacity is derived from hydro power plants and various renewable energy sources, including wind farms and PV panels (ERO, 2023). Unsustainable energy policies, lack of investment in new projects to meet the demand, dependence on old and highly polluting power plants, as well as high reliance on energy imports, especially during the winter season, and the variability of prices in the international electricity stock exchanges, have brought Kosovo's energy system to face challenges. This situation has an impact on the security of electricity supply (Gjukaj et al., 2024).

Utilization of these unused areas would not only be beneficial for reducing pollution, but also present an opportunity to refrain from using arable land for constructing PV parks. Agriculture stands as one of the main pillars of the country's economic development.

The agriculture sector continues to play an important role in Kosovo's economy by providing food, employment, and a sizeable percentage of the Gross Domestic Product (GDP); in 2020, the agricultural share of the country's GDP was around ten percent. On the basis of this importance, agricultural policies have become an increasingly key issue in Kosovan development policies (Ministry, 2022).

The typology of farms in Kosovo is based on agricultural and economic size, using the standard of production coefficients. Agricultural activity in Kosovo is carried out on farms characterized by diversity in terms of land used, production patterns applied, and geographical distribution. The study of farm typologies is focused on variabiles such as soil quality, socio-economic conditions, infrastructure, agricultural production and inputs, production profitability, and an index of agricultural benefits. Combining economic variables with non-economic variables to classify small farms provides insights for more effective farm classifications (Thomas et al., 2022).

In the EU documents outlining the 2050 perspective, the primary objectives are prioritized as follows: securing external supplies through international policies and infrastructure projects, enhancing the utilization of internal EU resources, boosting energy efficiency, fostering competitive conditions within the internal energy market, and mitigating carbon dioxide emissions (Wojtaszek et al., 2024).

Recent analysis of literature highlights the pressing need for innovative approaches in the realm of renewable energy as a pivotal response to the challenges posed by climate change. However, a notable gap in the existing literature pertains to the efficacy of environmental policies in driving progress within this sector. The insights gleaned from this domain suggest that fiscal incentives and emissions trading policies, such as those exemplified by the EU emissions trading system (ETS), consistently demonstrate a positive influence on innovations in renewable energy technologies. Conversely, the impact of incentive

tariffs and quotas aimed at supporting advancements in renewable energy exhibits variability, often yielding distinct effects across different geographical regions and within various segments of the renewable energy sector. Moreover, comprehensive analyses indicate that the combination of diverse policy measures may prove more effective in fostering innovation, compared to the implementation of standalone policies. This underscores the importance of adopting a multifaceted approach that integrates various policy instruments to stimulate innovation and drive progress towards sustainable energy solutions (Rastegar et al., 2024).

The Paris Agreement has garnered signatures from 195 countries and has been ratified or joined by 187 Parties to date, representing 97% of global greenhouse gas (GHG) emissions (World, 2019; Teske et al., 2019) With the exception of Kosovo, all Wester Ballkan (WB) countries have ratified the Paris Agreement, pledging to reduce their GHG emissions while sustaining satisfactory economic growth (Banja et al., 2020). In the Western Balkans, climate change is marked by a concerning rise in temperatures across the entire region. Projections indicate a temperature increase of 1.2 °C in the near future, with further warming expected to reach between 1.7 °C and 4.0 °C by the end of the century. This trajectory depends on the collective global efforts to reduce the greenhouse gas emissions (Vuković et al., 2018).

Kosovo has engaged in other regional initiatives such as the Sofia Summit and the Berlin Summit, taking responsibility to implement the European Green Agenda in cooperation with the countries of the Western Balkans. During the WB Summit in Sofia, Western Balkan leaders, including Kosovo, reaffirmed their commitment to align with the European Green Deal, emphasizing sustainability and resilience in priority sectors. They welcomed the Economic and Investment Plan for green socioeconomic recovery, aiming to transform the region into a climate-neutral and competitive economy. Leaders endorsed the Green Agenda for the Western Balkans, focusing on climate, energy, mobility, depollution, agriculture, and biodiversity. Agreements highlighted the commitment to combat climate change, align with EU policies, reduce emissions, and enhance governance. They pledged to work towards a carbon-neutral continent by 2050, promoting environmentally friendly practices in agriculture and biodiversity conservation. Strategies for biodiversity conservation, forest restoration, and nature-based solutions were prioritized. Regional cooperation, awareness-raising, and robust monitoring mechanisms were deemed essential for successful implementation, fostering sustainable development in the region (Sofia Declaration, 2020). During the WB Summit in Berlin on November 3rd, 2022, a declaration was endorsed for a carbon-neutral action plan by 2050, aligned with the Paris Agreement, European Green Deal, and Energy Community Treaty. This aims to bolster energy security, drive the green transition in the Western Balkans, and align with EU climate goals. The plan entails accelerating the Green Agenda, diversifying energy sources, enhancing efficiency, gradually phasing out coal, aiding vulnerable communities, promoting green investments, fostering regional cooperation, modernizing infrastructure, conducting impact assessments, and advancing a regional energy plan (Declaration on Energy, 2020).

Therefore, recognizing that constructing a solar panel center requires significant space, which is not readily available in Kosovo, the concept is to repurpose degraded and unusable lands from previous operations into pollution-free areas. Simultaneously, these areas would be remediated, eliminating them as sources of pollution, while generating clean electricity through PV panels.

SPVs offer significant environmental benefits compared to conventional energy sources, supporting ecological sustainability. However, technological innovations are essential to meet the growing demand for electricity while reducing carbon emissions. PV installations, requiring large areas of land, present various environmental challenges such as deforestation and pollution. Despite drawbacks such as low efficiency, PV systems offer advantages such as clean energy production and versatility in applications. The efforts to mitigate negative impacts and promote widespread adoption of solar energy are essential for global sustainability (Abid et al., 2023).

MATERIALS AND METHODS

The methodology discussed in the article focuses on the potential repurposing of current and former lands resulting from mining activities conducted by KEK near the capital city of

Pristina. Considering Kosovo's limited availability of undesirable lands, the methodology aims to optimize post-mining land use, enhance land value, and integrate degraded lands into regional planning for renewable energy generation. This research sought to utilize computer simulations to explore the feasibility of repurposing a segment of the Dragodan landfill, encompassing roughly 80 ha within a larger site of approximately 243 ha. This landfill originated from the deposition of fly ash residues from the "Kosovo A" Thermal Power Plant and the disposal of overburden generated by open surface mining operations conducted over past decades. Following the analysis of simulation outcomes, the intention was to extrapolate findings to guide the rehabilitation of similar degraded environments. The evaluation process considered the key criteria: location, geotechnical, topography, environmental risks, and the potential for solar energy development. The methodology can be customized to suit local conditions and provides valuable insights for decision-making regarding land repurposing, with a focus on reducing CO_2 emissions through the utilization of these areas for clean energy production.

Utilizing energy from renewable sources generally aids in reducing fossil fuel consumption, greenhouse gas emissions, and pollution, while also potentially saving costs. This study focused on analyzing the impact of a PV power plant on energy conservation and CO_2 emission mitigation, employing the RETScreen software package. Various parameters, including the technical specifications of the solar park, meteorological data, and radiation information, had to be considered for this analysis. Meteorological data were obtained from NASA and processed automatically by the software, while data on sunny days and radiation were sourced from the Meteorological Institute of Kosovo (Hydrometeorological, 2023).

To determine the installed capacity of PV systems in the designated area and estimate the annual energy output from PV installations, simulations were conducted using PVSOL software (PV*SOL premium 7.5 – Valentin Software GmbH) (Valentin Software, 2024). Additionally, the assessment of greenhouse gas (GHG) emission mitigation was performed using RETScreen International (Clean Energy Project Analysis Software), with further comparisons made against the outcomes from PVSOL software calculations (RETScreen, 2024).

RESULTS AND DISCUSSION

The modernization of Kosovo's energy sector is imperative for fostering sustainable growth. Despite achieving its renewable energy consumption target in 2020, transitioning away from lignite towards renewable sources is essential to maintain competitiveness with the EU and uphold commitments under the Energy Community Treaty (The Energy Community, 2004; RES Kosova, 2024). The recently introduced Kosovo Energy Strategy 2022–2031 emphasizes the need to increase the share of renewable energy sources while simultaneously addressing the social impacts associated with coal extraction and combustion (Energy Strategy, 2023). Kosovo currently relies heavily on outdated and environmentally detrimental coal-fired power plants, which supply approximately 93% of domestic electricity generation, this is illustrated in Figure 1 below (ERO, 2023; IEA, 2023). The new energy strategy outlines a gradual phasing-out of coal in favor of scaling up solar and wind power generation. However, active coal mines are expected to remain operational for several decades before eventual reduction and replacement with renewable energy alternatives (RES Kosova, 2024; Energy Strategy, 2023; Stanley et al., 2018).

The European Green Deal (EGD), with its ambitious target of reducing greenhouse gas emissions by 55% by 2030 (The European Green, 2019; Diana et al., 2023), presents a significant challenge for Kosovo. This challenge is compounded by the historical context of the development of Kosovo's energy sector, which has been largely reliant on fossil fuels, particularly coal. Kosovo has limited access to alternative energy sources, which further complicates its transition to a greener economy. Additionally, Kosovo's energy infrastructure is in need of modernization and expansion to support the integration of renewable energy sources. The EGD requirements necessitate a fundamental shift in Kosovo's energy policies, requiring substantial investments in renewable energy and energy efficiency measures (Simon, 2022). This transition is crucial not only for Kosovo's environmental sustainability but also for its economic development and energy security.

The efforts of the Energy Community to facilitate the energy transition of its member countries in line with the objectives of the EU Green Deal are evident. A decarbonization roadmap was adopted in 2021, outlining legislative and policy

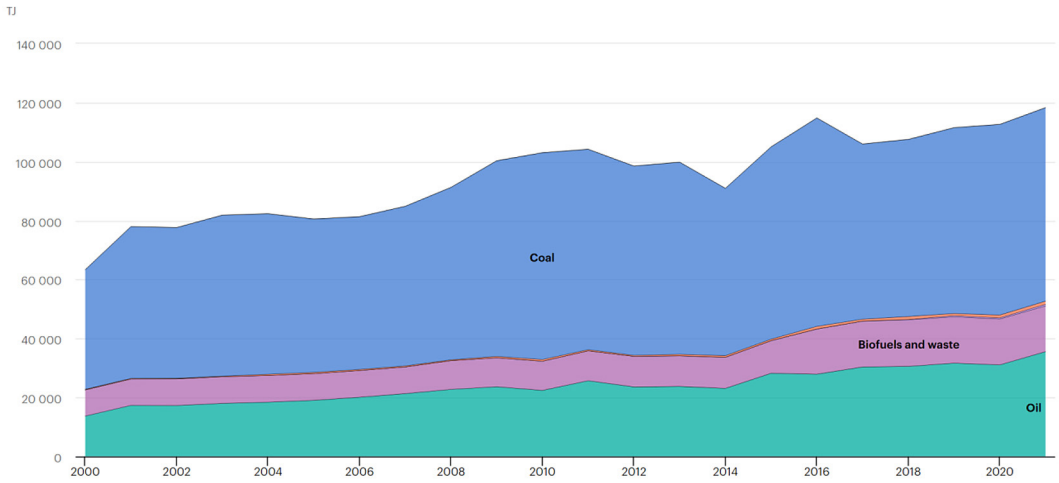

Figure 1. Total energy supply (TES) by source, Kosovo, 2000–2021

actions for 2030 and beyond. Western Balkan countries, including Kosovo, are working on their national energy and climate plans and transposing the EU Clean Energy Package into their national laws (National Energy, 2023). The leaders of the Western Balkans partnership have committed to aligning with the EU Climate Law and achieving climate neutrality by 2050. Another focus is on advancing the EU Emissions Trading System and carbon pricing, as outlined in the decarbonization roadmap (Decarbonisation, 2022).

Renewable energy policy and regulation in Kosovo: framework, obligations, and incentives

Renewable Energy Sources (RES) The Energy Law No. 05/L-081 defines the policy for the development of RES (Draft Law, 2020), aiming to promote the sustainable and economic utilization of local RES potentials to meet energy needs, enhance supply security, and protect the environment, which is an integral part of the Energy Strategy of the Republic of Kosovo (Energy Strategy, 2023). The relevant ministry, in line with current legislation, has set energy quotas from RES through a specific sub-legal act in harmony with the requirements of the relevant European Union directive for RES (Renewable Energy Directive, 2018). The Energy Regulator Law No. 05/L-084 specifies that the construction of new generating capacities (RES), new systems for the transmission and distribution of natural gas, including interconnectors, as well as direct electric and gas pipelines for natural gas transportation, will be carried out in accordance with the Authorization procedures under this law, to be undertaken by the Energy Regulatory Office, in line with objective, transparent, and non-discriminatory criteria (Law no. 05/l-084, 2022). It is worth noting that the Republic of Kosovo is a signatory to the Energy Community Treaty signed on October 25th, 2005, ratified, entered into force on July 1st, 2006, and started implementation on July 1, 2007 (The Energy Community, 2004). On the basis of this treaty, Kosovo has legal obligations to fulfill all obligations related to the energy sector, including the mandatory target for RES quotas by 2020, which includes the construction of new generating capacities from clean sources. To meet the legal obligations to achieve the mandatory RES target, the Ministry of Economic Development issued Administrative Instruction No. 01/2013 and amended it with Administrative Instruction No. 05/2017, setting annual and long-term quotas for RES energy (Administrative Instruction, 2013). The Administrative Instruction specified that the mandatory quota from Renewable Energy Sources until 2020 was 25% of the final gross energy consumption, as defined in Article 4 of the Ministerial Council Decision of the Energy Community No. D/2012/04/MC-EnC (D/2012/04/MC-EnC, 2009). In 2016, to support the development of investments in Renewable Energy, the Energy Regulatory Office set feed-in tariffs for electricity production from RES, with specific prices for different sources such as hydro, wind, solid biomass, and solar panels up to 10 MW (Feed-in Tariff, 2015). Additionally, to achieve RES objectives, the lifespan of the Power Purchase Agreement between the investor and KOSTT/TSO was guaranteed for 12 years for solar panels and wind

turbines, and 10 years for other sources like hydro and biomass (RES Kosova, 2023) (Figure 2).

Assessment of coal mining operations and land use rehabilitation

The Sibovc coal basin, located in Kosovo, currently serves as the sole operational mining site for coal extraction. This area is an extension to the northwest of the previously decommissioned Bardh and Mirash mines, which now function as overburden dump sites. This research article explored six distinct potential areas, totaling approximately 2700 ha, as depicted in Figure 3, each characterized by specific attributes (Orthophoto, 2019). The primary objective was to implement a pilot project within a designated 80 ha parcel, with the potential for future expansion into additional regions.

Former ash dump "Kosova A" (1A) and Dragodan outside overburden dump (1B) have a ground surface area of approximately 240 ha.

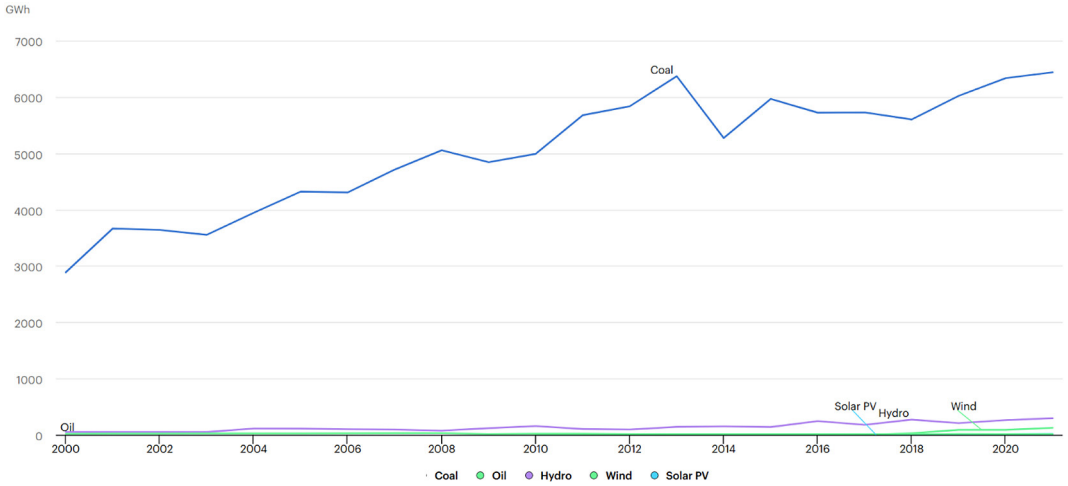

Figure 2. Electricity generation by source, Kosovo, 2000–2021

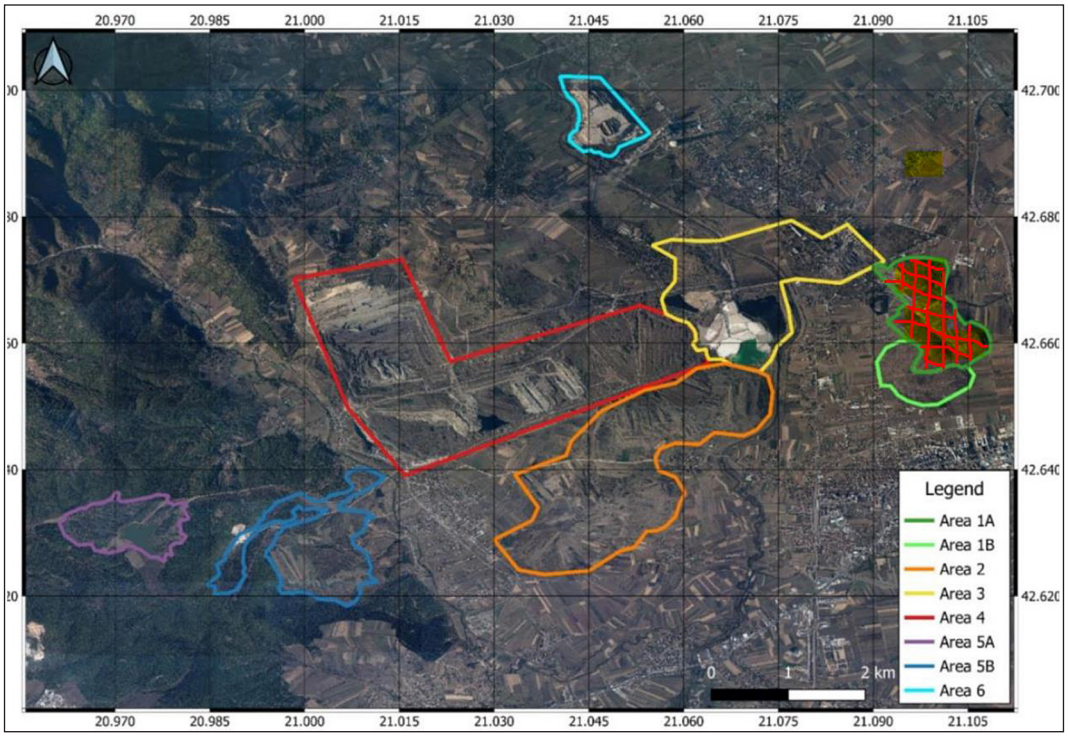

Figure 3. Six areas of mining and post-mining lands with potential for PV deployment (Base Map: KEK Orthophoto Images)

The south outside overburden dump covers an area of around 613 ha. The areas designated for liquid fly ash deposition, municipal waste landfill, overburden dump Palaj, and the gasification plant have a combined ground surface area of approximately 409 ha. Bardh and Mirash mined-out open pits, along with the currently active Sibovc coal mine, encompass a ground surface area of about 948 ha. Former outside overburden dumps Vasilev (5A) and Kalaja (5B) cover approximately 324 ha in total. Lastly, the "Kosova B" Ash Dump has a ground surface area of around 93 ha (Worldbank-Project, 2016).

Site description

The selected area for simulation is situated near the capital of Pristina, where ambient pollution exhibits a heightened concentration in comparison to other regions across Kosovo. Furthermore, prioritization of infrastructure development for connectivity to the existing network is underscored by the close proximity of the space to pre-existing energy infrastructure. Notably, unimpeded access to the field obviates the necessity for expropriation, and its adjacency to two state-owned power plants facilitates the utilization of available resources to streamline the establishment and operation of the PV Plant. The geographic coordinates and elevation of the site are delineated in Table 1.

Table 1. Coordinates and altitude of select project site

Latitude	Longitude	Elevation
42.660532N	21.102673E	584 m.a.s.l.

Surrounding land parcels adjoining the project site are under private ownership and predominantly utilized for agricultural purposes. Satellite imagery reveals the presence of modest settlements and rudimentary structures within the vicinity (Figure 4). The chosen site is situated to the east of the "Kosova A" Thermal Power Plant, approximately 1 km away. Encompassing an area of 243 ha, the entire landfill and waste area have accommodated ash deposition since the inception of operations at the "Kosova A" Thermal Power Plant in 1962 (Worldbank-Project, 2016). The physical dimensions of the landfill are delineated as follows:

- the longitudinal extent from south to north spans 2600 m;
- the average latitudinal width from east to west measures 1230 m;
- the perimeter of the landfill encompasses a distance of 8152 m;
- the total land area occupied by the landfill is 243 ha.

Of the overall expanse, roughly 163 ha of the landfill surface are overlaid with deposited ash, while the remaining 80 ha earmarked for PV installation are filled with discarded waste. Among these, approximately 143 ha are layered with a combination of soil and waste, leaving approximately 20 ha uncovered.

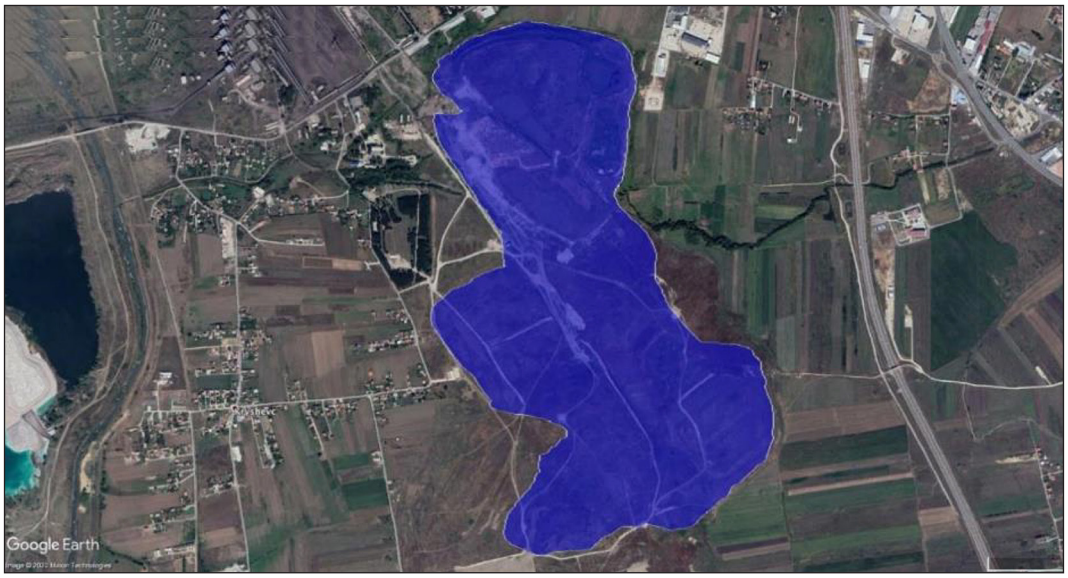

Figure 4. Project site location (source: Google Earth)

The simulation relies on comprehensive meteorological input data, as outlined in Table 2. These data encompass a wide spectrum of meteorological parameters, crucial for a thorough understanding of the system's operational dynamics. Variables, such as weather patterns, ambient temperature, wind speed, and rainfall levels, are meticulously recorded and analyzed. Their collective influence is paramount in shaping the dynamics of the system's electricity production. Consequently, this detailed analysis serves as a foundational pillar in the modeling and accurate forecasting of the system's energy production, thereby facilitating future decision-making processes and providing valuable insights for energy management and policy formulation aimed at promoting. environmentally friendly production practices.

Simulation

The PVsyst simulation software was used to estimate the energy yield. The simulation relies on hourly meteorological input data, including radiation and temperature values, to determine the electricity output of the system. Consequently, the PV plant is modeled based on several assumptions, such as available space, plant size and capacity, module and inverter type, electrical layout, and overall plant configuration. Moreover, pertinent loss factors arising from the plant's location, components, and configuration are evaluated and incorporated into the simulation (Table 3). The coefficient for CO_2 emissions associated with electricity consumption by end-users stands at 1.438 (Diana et al., 2023), as determined by the Ministry of Environment and Spatial Planning. Consequently, the establishment of the PV solar park is anticipated to mitigate CO_2 emissions by an estimated 136,877.4 metric tons annually. To elucidate the significance of this reduction, it can be likened to the emissions from vehicular sources. Hence, with an electricity production capacity of 80 MWp from the PV system, the reduction equates to the emissions akin to approximately 65,850 cars annually. The outcomes of the software simulations are illustrated in Figure 6.

The use of the latest technology, with affordable costs and enhanced efficiency, has heightened the demand for commissioning energy production capacities reliant on renewable sources, particularly solar energy. In another vein, when contemplating the requirement for expansive land areas for PV farm construction, especially within the context of limited space and the imperative to conserve natural resources, installing solar panels on degraded surfaces emerges as a favorable option. This form of installation presents numerous advantages over erecting photovoltaic farms on agricultural land or other vital spaces, offering a sustainable solution for society at large.

Table 2. Weather parameters in selected area

Climatic factors	Meteorological parameters
Climatic characteristics	The climatic conditions of the TC-A ash dump area closely resemble those of the Pristina and Kastriot territories.
Temperature	The average temperature for winter (December-February), spring (March-May), summer (July-August), and autumn (September-November) are as follows: 0.20 °C, 9.70 °C, 19.50 °C, and 11.20 °C, respectively.
Wind	The most pronounced types of winds are northeast with 20.3%, north with 19.4%, and western winds with 50% of occurrences. The average wind speed measured is 3.2 m/sec.
Precipitation	The average annual rainfall reaches 576 mm, with a maximum of 755 mm and a minimum of 381 mm. The highest monthly rainfall recorded is 157 mm.

Table 3. Simulation results

PV system	
Pv generator output	80000.3 kwp
Specific annual yield	1,191.70 kwh/kwp
Performance ratio (pr)	83.6 %
Grid feed-in	95,336.169 kwh/year
Grid feed-in in the first year (incl. module degradation)	95,336.169 kwh/year
Stand-by consumption	92,735 kwh/year
Co_2 emissions avoided	136,960.059 kg/year

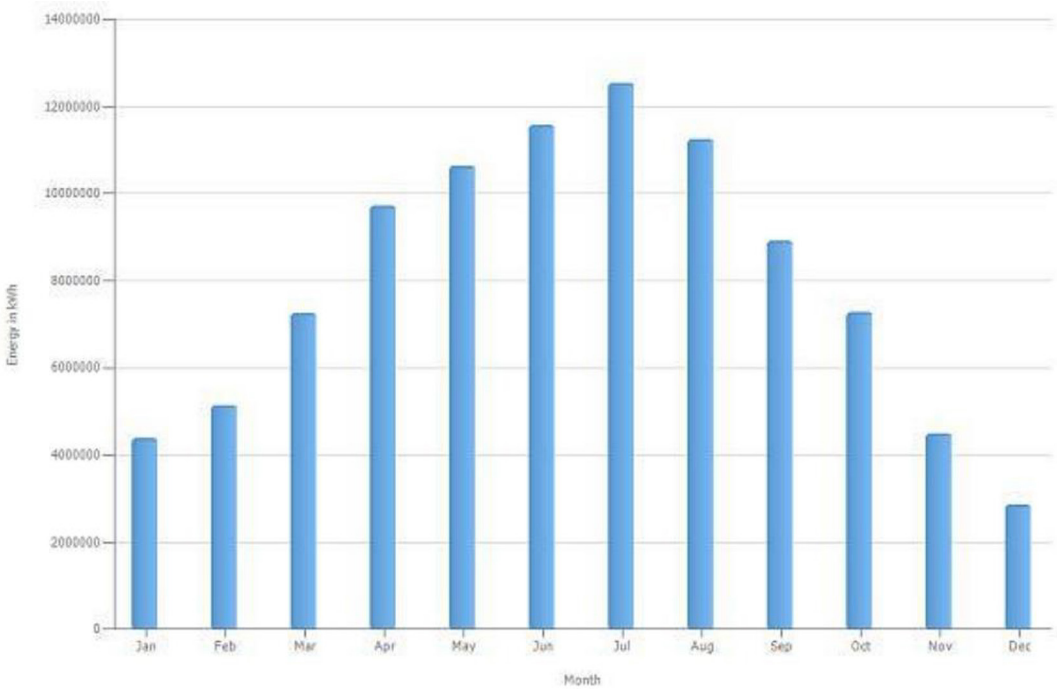

Figure 5. Yearly forecast production

Base case electricity system (Baseline)

Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
Albania	All types	1.438		1.438

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100.0%	95,186	1.438	136,877.4
Total	100.0%	95,186	1.438	136,877.4

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	136,877.4	0.0	136,877.4		136,877.4

Net annual GHG emission reduction	136,877	tCO2	is equivalent to	12,589	Hectares of forest absorbing carbon

Figure 6. Net annual GHG emission reduction

CONCLUSIONS

The research focused on the potential utilization of the Sibovc coal basin in Kosovo, currently operating as the primary mining site for coal extraction. Through exploration of six prospective areas totaling approximately 2700 ha, the study aimed to implement a pilot project within an 80 ha parcel, with future expansion potential. The geographic location near Pristina and its proximity to existing energy infrastructure underscore the strategic importance of infrastructure development, facilitating the establishment of a PVplant. Despite the challenges related to land availability, particularly in contexts with limited space and the imperative of resource preservation, the installation of solar panels on degraded surfaces emerges as a promising alternative.

The simulation process, conducted using the PVsyst software, assesses the energy yield potential of the PV system based on hourly meteorological input data, including radiation and temperature values. Assumptions regarding plant specifications, layout, and configuration are incorporated into the modeling process, alongside considerations of loss factors. The simulation results demonstrate a specific annual yield of 1,191.70 kWh/kWp, with a projected CO_2 emissions reduction

of approximately 136,877.4 metric tons annually. This reduction, equivalent to the emissions from tens of thousands of cars, underscores the environmental benefits of renewable energy adoption, particularly solar power, in mitigating greenhouse gas emissions and promoting sustainability. The adoption of advanced technology in renewable energy, coupled with its cost-effectiveness and efficiency, has accelerated the demand for energy production capacities reliant on solar energy. Installation of solar panels on degraded surfaces presents a viable solution, offering advantages over traditional PV farm construction methods. This approach not only addresses land scarcity concerns but also contributes to the environmental conservation efforts, offering a sustainable energy solution with far-reaching societal benefits.

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