Solar and Wind Power – Sustainability at UB-FME

JELENA M. SVORCAN, University of Belgrade,
Faculty of Mechanical Engineering, Belgrade
ORCID: 0000-0002-6722-2711
MILAN I. LUKIĆ, Technical secondary school, Stara Pazova

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To stimulate and facilitate the transition to a more sustainable and cleaner future, several renewable energy possibilities (wind and solar in particular) are considered for the University of Belgrade, Faculty of Mechanical Engineering (UB-FME). The paper presents an initial study of the possible energy contributions that could be achieved in the near future by distributing solar panels or small wind turbines across the rooftop surface, in addition to improved education and raising awareness of the sustainability related issues in general public. The initial estimates indicate that an additional 30-300 MWh could be generated annually, but further socio-techno-economic analyses should be conducted.

Key Words: *sustainability, solar panels, small wind turbines, renewables, AEP*

1. INTRODUCTION TO SUSTAINABILITY

Sustainability is one of the most employed words in contemporary research publications [1-8], and for several good reasons. The growing world population and energy demands call for continual and feasible technical and engineering solutions, that can increase life quality while maintaining our natural surroundings. Several global initiatives are being actively promoted, such as the Paris Agreement, the European Green Deal (with the ambition to reduce emissions by at least 55% by 2030 and 90% reduction proposed for 2040) [9], the United Nations' Sustainable Development Goals (SDGs) [10], etc. They all formulate ambitious goals of reducing energy consumption and emissions as well as increasing the share of renewables in energy production [11] which must also be accompanied by detailed sociotechnical analyses and improved and reformed education [2]. Figure 1 illustrates the increasing global trends of using solar and wind power for electricity generation [11].

Unfortunately, data statistics for Serbia confirm that the number of wind and solar farms remains low. The share of all renewables in the total electricity gene ration was a mere 5.4% in 2024. Of that number, only 3% came from wind, and miniscule 0.05% from solar resources [12]. The distribution of renewables in Serbia is depicted in Figure 2.

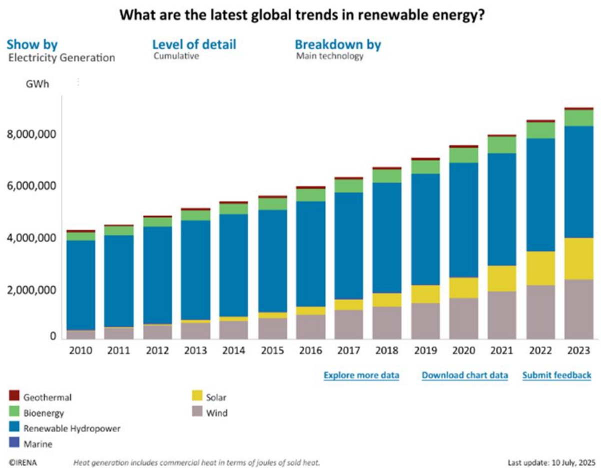

Figure 1 – Rising global trends of employing the renewables [11]

Some studies indicate that, in the EU, nearly 40% of energy consumption and 36% of CO2 emissions are produced by buildings [13]. Since they constitute a large energy consumer, for an efficient answer to the climate change threat we need to adopt some novel technologies and apply them to the existing infrastructure. Up to now, sustainability in Serbia has mostly been considered in the areas of transportation and urbanism [13-15]. For that reason, this paper aims to examine some additional sustainable solutions that could be applied at the University of Belgrade, Faculty

Author`s address: Jelena Svorcan, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Kraljice Marije 16

e-mail: jsvorcan@mas.bg.ac.rs

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of Mechanical Engineering (UB-FME) from the perspective of mechanical engineers. In the future, some of the mentioned possibilities might prove convenient for other educational institutions also (from kinder gardens to elementary and secondary schools, as well as other faculties and universities).

Figure 2 – Current share of energy production sources/generators in Serbia [12]

To ensure a successful energy transition, energy efficient and sustainable solutions need to appeal to and attract everyone, from children to elderly people, laymen and experts included. Therefore, this process can be facilitated by first testing some of these state-of-the-art solutions/concepts at the existing, commendable educational institutions that have a long tradition and can widely influence the general public.

2. SUSTAINABILITY AT UNIVERSITIES

To promote sustainability, reduce operating costs and reduce environmental impact universities worldwide are increasingly using renewable energy sources [1-8]. Depending on the location and available space, they mostly use rooftop solar panels, small wind turbines and biomass. On campuses, they tend to develop their own microgrids [3], but also use new infrastructure for research, education and promotion of sustainability and green agenda.

Main benefits of promoting sustainability at universities include:

- considerable cost reduction/savings (long term),
- improved and state-of-the-art education (students have the opportunity to familiarize themselves with sustainable technologies right from the beginning of their professional life and be involved in all phases of mechanical design, including initial calculations, production and assembly, performing measurements, data analysis, optimization, etc),
- regional leadership in reducing carbon footprint.

Main disadvantages comprise:

- increased initial investments (short term),
- sophisticated energy management systems are an additional requirement,
- energy storage systems are also required (they, on the other hand, call for dealing with safety issues, regular maintenance, additional costs),
- systemic change (on the faculty and university level) is necessary.

So far, the most common solutions have incorporated:

- solar photovoltaics (PVs), usually distributed in rooftop arrays, on parking canopies, or as ground-mounted systems, depending on the available space, roof condition, local sunlight intensity, etc,
- wind turbines (WTs), usually found on larger campuses or in rural locations, depending on the available wind speed; they also raise some noise concerns, and have a visual impact.

Supplementary options and measures may include: recycling, increased employment of new materials – composite or plastic [16,17], green roofs, enabled cycling (i.e. transportation improvements, particularly electric vehicles), garbage management, etc.

3. SUSTAINABLE POSSIBILITIES AT THE FACULTY OF MECHANICAL ENGINEERING IN BELGRADE

As is probably well known, the University of Belgrade is not concentrated within a single campus but dispersed around the capital city. This means that every faculty/school and institute must formulate its own strategy and future goals/steps on the path to sustainability.

One of the main features of the spacious building of the Faculty of Mechanical Engineering in Belgrade is that it is located downtown and surrounded by numerous buildings (that affect the airflow as illustrated in Figure 3). Also, it was built in the fifties when energy efficiency issues were not particularly addressed. It has a large usable area distributed along two underground and five aboveground levels.

Its length (along the street Kraljice Marije) is roughly 120 m, while its width is around 17.5 m, which results in the main rooftop area of nearly 2.100 m^2, with an additional 800 m^2 covering the side wings of the main building and including the roof of an adjacent, auxiliary building (where subsonic wind tunnel is located). UB-FME presents a considerable energy consumer (accommodating three amphitheaters and numerous classrooms, offices, laboratories, large pieces of valuable equipment, restaurant, student café, library, etc) with substantial average monthly consumption, where every cost cut and energy saving counts.

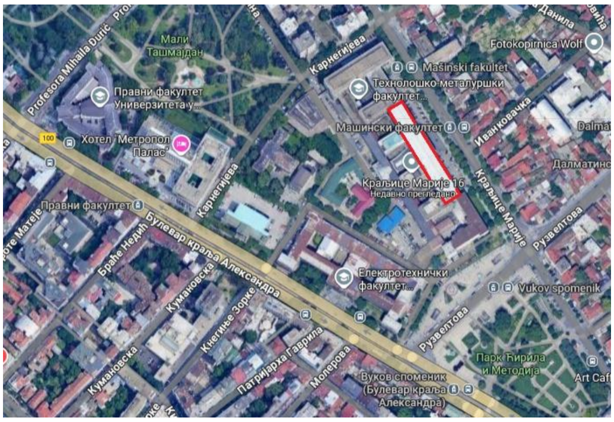

Figure 3 – Rooftop area of the Faculty of Mechanical Engineering in Belgrade

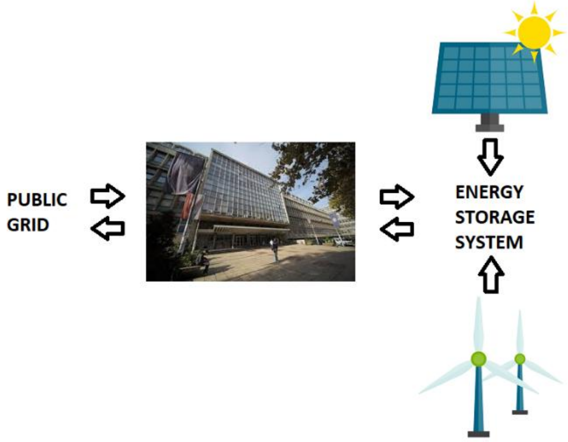

Figure 4 – Schematic of the proposed system

Given the large rooftop area, and limited available space around the building, the two most viable options for UB-FME are solar panels [18] and small wind turbines [19]. A schematic of the proposed system is illustrated in Figure 4. Additionally, the faculty may also serve as a convenient testbed for sustainable energy management. Any surplus energy may also be used for electric charges (for both road and aerial electric/hybrid vehicles).

3.1 Estimated energy from PVs

An adequate PV system is mostly determined-/limited by the energy needs, available space, efficiency of solar panels, solar irradiance conditions at the installation site and some additional correction factors that account for the shading, dirt, cable losses, aging, etc.

For the purpose of this initial study, we perform a simple estimation of the nominal capacity of the PV system potentially installed at UB-FME. We assume that approximately 70% of the rooftop surface may be used, which gives an affective area of 1500 m^2, with the potential expansion to 2000 m^2. Nominal capacity assumes standard operating conditions – direct solar radiation of 1 kW/m^2, temperature 25°C and no wind, and we adopt a conservative value of the solar panel efficiency of 0.16. Multiplying these three terms, we reach the nominal capacity of Y_{PV} = 240 kW$_p$ (with the option to be extended to 330 kW$_p$).

Real power production will depend on the location, season, time of day, etc. To get an initial educated guess, we employ the Global Solar Atlas [20], as illustrated in Fig. 5. For Belgrade, average specific photovoltaic power output is PVOUT = 3.56 kWh/-kW$_p$/day, meaning that on average we may generate over 800 kWh daily with our PV system.

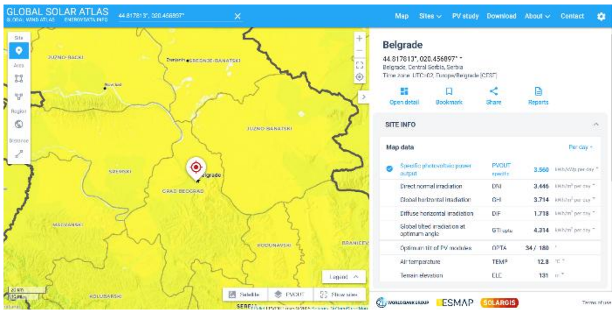

Figure 5 – Averaged solar conditions in Belgrade

However, given that the solar conditions considerably fluctuate during the day and year, as illustrated in Figure 6, we can roughly estimate the annual energy production of our PV system to 300 MWh. Similar results can be obtained if we employ NREL's PVWatts® Calculator [21]. Temperature effects, although they may be significant in real operation, are neglected at this stage.

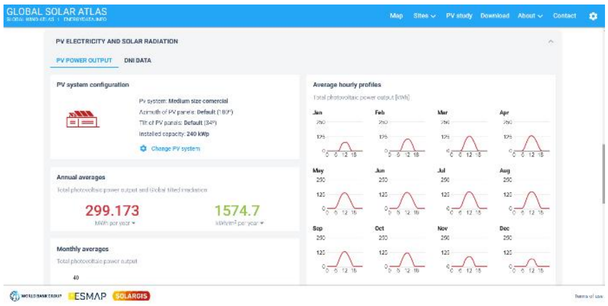

Figure 6 – Daily and annual fluctuations of solar irradiation and PV power output

3.2 Estimated energy from WTs

For the estimation of power produced by wind turbines, mean wind speed at the hub height is imperative. Even though urban surroundings are considered, and Belgrade generally has a poor wind resource, the small/micro wind turbines would be located on the faculty rooftop (at the height of 20-30 m), where somewhat higher wind speeds may be expected. Initially, they can be estimated according to the power or logarithmic law, if we know the mean wind speed at a reference height. Using the Global Wind Atlas [22] (as illustrated in Figure 7) and data available from the Republic Hydrometeorological Service of Serbia [23], we may expect an average wind speed of V_{ref} = 2.3 m/s at the height of H_{ref} = 10 m.

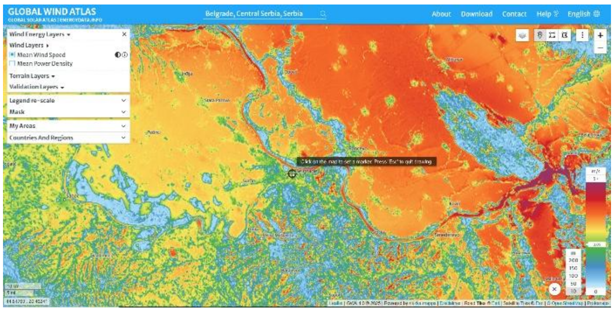

Figure 7 – Mean wind speed in Belgrade and Central Serbia

Assuming a highly rough terrain (city centre), we adopt the characteristic roughness length of z_o = 1 m, and calculate an averaged wind speed profile (with respect to height), Fig. 8, using Eq. 1. At the height of H = 25 m we may expect wind blowing at an average speed of V = 3.2 m/s.

$$V = V_{ref}\frac{log\frac{H}{H_{ref}}}{log\frac{z_o}{H_{ref}}} \qquad (1)$$

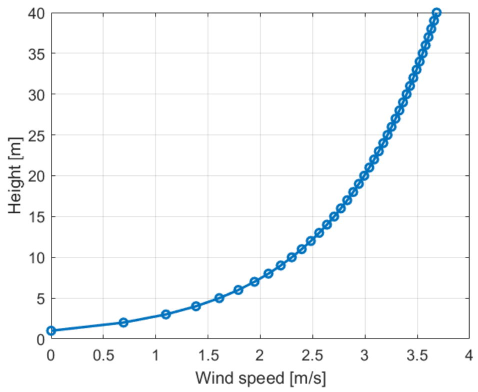

Figure 8 – Mean wind velocity profile with height around UB-FME

Power per turbine can be estimated according to Eq. 2, where ρ is the air density, A rotor area and C_P power coefficient that is dominantly influenced by the geometry (aerodynamic performance) of the blades.

$$P = C_P \rho A V^3 \qquad (2)$$

The next decision that should be made refers to the wind turbine type, horizontal - (HAWT) or vertical-axis (VAWT). HAWTs are still a more common solution, as they are generally more aerodynamically efficient, but are more complex, and affected by the wind direction as well as the shed wakes. Since wind direction is also rather variable around UB-FME, VAWTs (as omnidirectional) might present a more convenient initial solution. Their other advantages include lower material costs, simpler structure, fewer parts, lower cut-in speeds and reduced noise (that is also an important constraint in urban environments). We can perform initial power estimates for both types by assuming diameter no greater than D = 2 m, and adopting conservative values for power coefficient C_P of 0.4 and 0.35 for HAWTs and VAWTs, respectively. In both cases, given the low value of wind speed, we obtain around 100 W per turbine.

If we assume that we can distribute at least 28 wind turbines along the circumference of the rooftop at an average distance of 10 m between the two, we can estimate the annual energy production AEP from wind to approximately 25-30 MWh, which roughly presents a tenth of the value we may expect from solar panels. The main reason for this great discrepancy is that the available wind resource at the location of UB-FME is much lower than the available solar resource. Additionally, the proposed PVs would cover a greater portion of the rooftop surface than the proposed WTs since their mutual effects would have to be studied with much more care in the future design phases. Also, there are some possibilities to enhance the aerodynamic efficiency of WTs that could be explored further in the future by the team at the Department of Aerospace Engineering at UB-FME [24,25].

It should also be mentioned that this initial calculation does not consider temporal variability of wind speed, that should also be considered in more detail in the future. Just a glimpse regarding this issue is illustrated in Figure 9 where both wind speed and insolation (hours of sunlight) measured and averaged in 2023 [23] are illustrated.

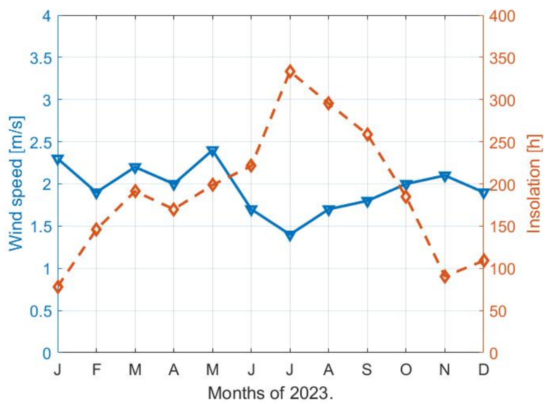

Figure 9 – Average wind speed and insolation in Belgrade in 2023 [22]

An interesting piece of information may also be observed, that wind speeds are the highest in the springtime, while solar irradiance is the greatest in the summertime, as expected. This opens additional possibilities to combine the two resources.

3.3 Additional considerations (components)

Some additional considerations should be made in future studies, primarily regarding the accompanying energy storage system (electric components) necessary when there is surplus energy during peak production periods but also during off-load conditions. It would be defined/limited by its maximal capacity, maximal charging rate, maximal current and voltage. Its more detailed design should be performed after completely defining the possible renewable energy sources.

Also, given that UB-FME is connected to public grid, an energy management system would have to be optimized. A similar study has been performed at the University of Coimbra where a microgrid constituted by photovoltaic generation, lithiumion battery storage, unidirectional and bidirectional charging of electric vehicles and controllers for the space conditioning systems has been implemented [3].

The ultimate goals that would govern this project further include:

- achieving (at least partial) energy autonomy of UB-FME,
- improvement of educational environment and foundation of „living laboratories“ where students would be actively involved in all design and maintenance phases,
- applying similar solutions to other faculties/-schools of the University of Belgrade, and beyond,
- raising awareness of renewables and sustainability.

4. CONCLUSIONS

The most important conclusions may be summed up as follows:

- By employing renewable energy solutions at UB-FME (in particular solar and wind power), an additional 30-300 MWh could be generated annually.
- There would be numerous benefits for students, such as acquiring hands-on experience and contemporary knowledge in diverse research and engineering areas such as mechanical design and optimization, production and assembly, big data analysis.
- There might also be some downsides for the neighbors of UB-FME, particularly regarding noise and „visual“ pollution.
- UB-FME could set an example for other educational institutions and provide guidance/assistance in creating high quality (greener, cleaner, sustainable) urban spaces/areas.
- More detailed future research studies, that take into account multidisciplinary aspects (social, technological, economic), are necessary.

5. ACKNOWLEDGEMENT

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REZIME

SOLARNA I ENERGIJA VETRA – ODRŽIVOST NA UB-MF

Da bi stimulisali i olakšali prelaz ka više održivoj i čistijoj budućnosti, nekoliko obnovljivih izvora energije (naročito energija vetra i sunca) je razmatrano zarad primene na Univerzitetu u Beogradu – Mašinskom fakultetu (UB-MF). Rad predstavlja početnu studiju mogućih energetskih doprinosa koji su ostvarivi u bliskoj budućnosti instalacijom solarnih panela i/ili malih vetroturbina po krovnoj površini, pride poboljšanog obrazovanja i podizanja svesti šire javnosti u vezi sa pitanjima održivosti. Početne procene ukazuju da bi dodatnih 30-300 MWh moglo da bude generisano na godišnjem nivou, ali dodatne socijalno-tehničko-ekonomske analize treba da budu sprovedene.

Ključne reči: *održivost, solarni paneli, male vetroturbine, obnovljivi izvori energije, godišnja proizvodnja energije*