



SOLAR ENERGY IN RURAL AREAS: POTENTIAL AND CHALLENGES

S. Lavchiev, R. Beluhova-Uzunova*

Department of Economics, Agricultural University – Plovdiv, Plovdiv, Bulgaria

ABSTRACT

The green transition is a key global focus, and solar energy has a significant potential for transforming rural areas by providing sustainable and decentralized resolutions. Analyzing the renewable energy implementation opportunities could help develop sustainable trajectories for the future of renewables most suitable in each region. This survey applies a policy-oriented methodology to explore the key factors and links, influencing of solar energy. The paper aims to observe the potential of renewable energy sources in the EU's rural areas, focusing on solar energy in Bulgaria. The results indicate that the EU contains substantial yet underutilized capacity for renewable energy expansion, which could be effectively achieved while maintaining a balance between energy transition goals, environmental and agricultural sustainability. In addition, local communities in rural areas are crucial drivers for building and promoting renewable energy. However, despite its potential, the adoption of solar energy in rural areas faces a number of challenges, such as high initial investment costs, infrastructure issues and regulatory barriers. By addressing existing obstacles, governments and stakeholders can unlock the benefits of solar energy, contributing to resilience, sustainability, and better employment opportunities in rural communities.

Keywords: green transition, sustainability, local communities

INTRODUCTION

The green transition is a key global focus, and solar energy has a significant potential for transforming rural areas by providing sustainable and decentralised solutions. The European Union made substantial efforts in this direction to respond not only to climate change, but also to resilience, competitiveness and revitalisation of rural regions. (1). Although there is considerable improvement in implementing renewable energy in the EU, rural areas face challenges such as energy poverty, infrastructure issues, and limited access to services (2, 3).

Solar power is considered an option for diversification and better access to clean and affordable energy (4, 5). Small-scale photovoltaic systems, agrivoltaics, and community initiatives offer new opportunities to support local economies in rural areas (6, 7). In addition, key strategic documents as the

European Green Deal and the REPowerEU plan promote solar technologies for achieving energy security and decarbonisation in rural areas (8).

The study aims to observe the potential of renewable energy sources in the EU's rural areas, focusing on solar energy in Bulgaria.

By analysing existing EU strategies, the research follows the academic and policy debate on how rural solar energy can be scaled up in line with the EU's climate and development goals.

MATERIALS AND METHODS

The survey applies a policy-oriented research design to assess the prospects and challenges of solar energy development in rural areas of the European Union. The analysis is based on the framework developed by Perpiña Castillo et al. (9), emphasising regional disparities in renewable energy potential and infrastructure. The study applies qualitative document analysis of key EU policy and legislative instruments relevant to promoting solar energy in rural contexts. The key policies include strategies such as the European Green

*Correspondence to: Rositsa Beluhova-Uzunova, Department of Economics, Agricultural University – Plovdiv, 12 Medeleev Bld., 4000 Plovdiv, Bulgaria, e-mail: rbeluhovauzunova@gmail.com

Deal (10), the REPowerEU Plan (11), and the EU Solar Energy Strategy (12), as well as regulatory frameworks including the Renewable Energy Directives (Directive (EU) 2018/2001; Directive (EU) 2023/2413) and the Energy Communities Directive (13,14)

The study is based on data from Eurostat (15), Ember (16). The methodology includes the structural conditions shaping solar energy implementation and the link between policy design, regional capacity, and local engagement.

RESULTS AND DISCUSSION

Trends in solar energy dynamics

The ambitious goals set in the Green deal related to climate-neutrality by 2050 require measures to boost a sustainable green transition. The implementation of renewable energy has many benefits related to reducing greenhouse gas emissions, decreasing fossil fuel

dependency, creating new employment opportunities and stimulating rural economies. According to Eurostat data (15), in the EU, the share of renewables in gross final energy consumption is 24.5%, three times higher than in 2004. Based on EU Directive 2023/2413 on the promotion of energy use from renewable sources, the 2030 renewable energy target is 42.5%. Therefore, the Member States must intensify their actions to increase the share of renewable energy sources by 20 pp. The set ambitions are high and require serious efforts in the coming years.

Sweden is the member state with the highest share of renewables, with more than 66.4%. According to the Eurostat data (15), Sweden's renewable energy mix includes biofuels, hydro and wind. Finland ranks second, followed by Denmark (45%). The lowest shares of renewable energy in gross consumption are registered in Luxembourg (12%), Belgium (15%) and Malta (15%).

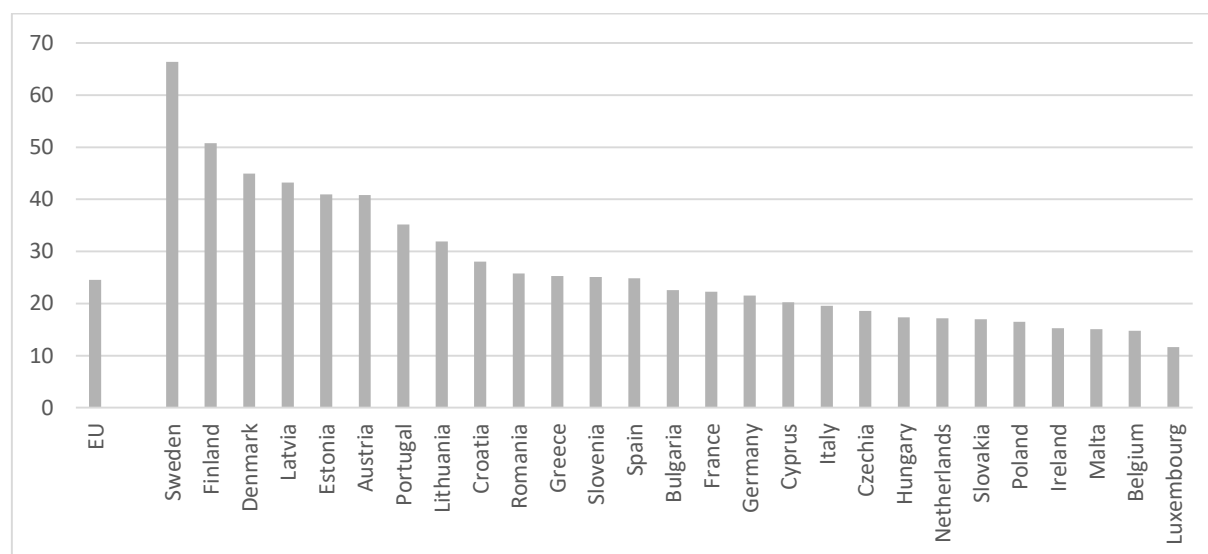


Figure 1. Share of energy from renewable sources, share in energy consumption (%), 2023

Source: Eurostat Statistics Explained (15)

According to Eurostat data (15), from 2013 to 2023, the increase in electricity generated from renewable sources is based on wind and solar power growth. Wind and hydro sources form around 67% of the total electricity generated from renewables, followed by solar power (21%). Solar energy is the fastest developing source, from 7.4 TWh in 2008 to 252.1 TWh in 2023.

In the context of fossil fuel-based electricity generation, coal accounts for approximately 10% of the total energy mix in the European

Union, whereas Bulgaria demonstrates greater dependence. Gas forms 16% of the EU's electricity production and only 5% in Bulgaria. Generally, the EU shows a more diversified and balanced use of fossil fuels. At the same time, Bulgaria's energy mix remains heavily dominated by coal.

Nuclear energy has a central position in the electricity generation portfolios of both the EU and Bulgaria. However, its significance is notably greater in the Bulgarian context.

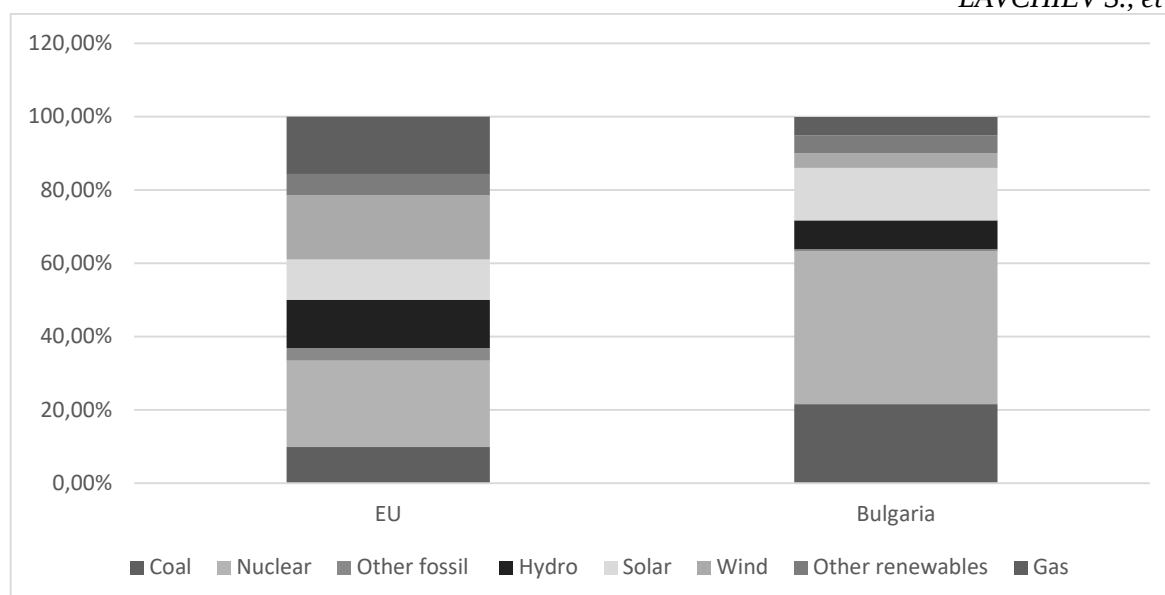


Figure 2. Energy mix in the EU and Bulgaria, share in produced energy (%), 2024

Source: Ember Climate (16)

The Ember data (16) compares the electricity generation mix between the European Union and Bulgaria based on the share of different energy sources.

Hydropower contributes to 13% of the electricity generation in the EU, compared to 8% in Bulgaria, reflecting a comparatively lower utilisation of hydroelectric resources in the country. Solar energy accounts for 11% of the EU's mix and 14% in Bulgaria, slightly exceeding the EU average.

Wind energy, forming 18% of electricity production in the EU, represents only 4% in Bulgaria. This significant difference indicates untapped wind energy potential in Bulgaria. Other renewable sources, such as biomass and geothermal, contain 5.8% of the EU's energy

mix and 4.9% of Bulgaria's, showing marginal variation.

In summary, Bulgaria has higher relative shares of coal, nuclear, and solar energy than the EU average. In comparison, the EU presents substantially higher gas, wind, hydro, and other fossil fuel shares. These disparities emphasise the structural differences in the energy mix of Bulgaria and the EU, with implications for future energy diversification and sustainability strategies.

Bulgaria's electricity mix is dominated by coal and nuclear power. Solar energy performs relatively well, but wind and hydro are underdeveloped. Bulgaria shows less diversity in its energy portfolio and significant potential for growth in clean technologies such as wind power and hydropower compared to the EU-27.

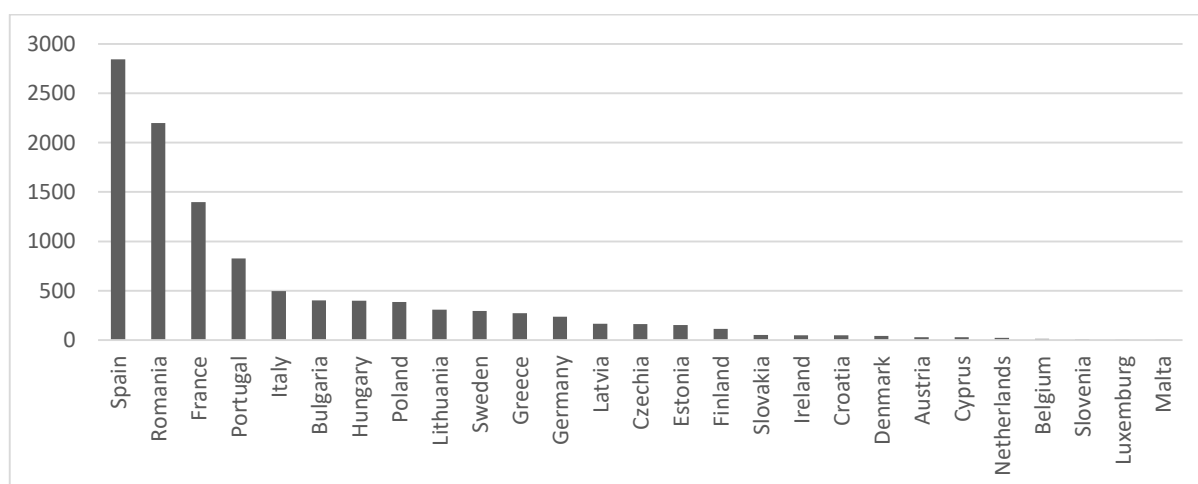


Figure 3. Untapped solar PV potential production in the EU Member States (TWh/year)

Source: (9)

The methodology presented by Perpiña Castillo et al. (9) defines "untapped potential" as "the discrepancy between the technical potential, defined as the maximum theoretically achievable electricity production and the current levels of solar electricity generation". The untapped solar potential in the EU is estimated at approximately 11,000 TWh per year. A considerable share of EU municipalities (95%) still have untapped solar capacity, with the highest levels observed in Spain, Romania, and France.

Geographically, the distribution of this untapped potential is concentrated in rural regions, which account for 78% of the total, followed by towns and suburbs (18%) and cities (4%). Rural areas' dominance also includes land availability. Rural areas contribute an estimated 8,600 TWh/year of untapped solar potential. Moreover, they have the highest mean annual

potential production per unit area. In Bulgaria, the share of untapped potential in rural areas is lower than the EU average. However, the suitable land and current production are higher than the EU-27.

Nevertheless, the strategic utilisation of untapped solar resources, particularly in rural areas, could significantly support the EU's energy transition goals and contribute to the European Green Deal's objectives, while maintaining the socio-economic benefits of renewable energy locally.

Policy context, drivers and challenges

The European policies framework highlights the landscape designed to promote the implementation of solar technologies in rural areas. These strategies combine climate, energy, agricultural, and regional development objectives.

Table 1. Policy context in promoting solar energy and relevance to rural areas

Policy	Year	Main Objective	Relevance to Rural Solar Energy
European Green Deal	2019	Achieve climate neutrality in the EU by 2050	Clean energy as a pillar of rural resilience and decarbonisation
REPowerEU Plan	2022	Enhance energy independence; accelerate renewables	Stimulates rooftop solar including in rural buildings; funds for local solar deployment
Fit for 55 Package	2021–22	42.5% renewable share by 2030	Supports decentralized solar systems and rural contributions to national targets
Common Agricultural Policy	2023–27	Modernize agriculture and rural areas	Funds renewable energy, energy efficiency, smart rural infrastructure
EU Rural Vision 2040	2021	Thriving, connected, resilient rural areas	Highlights green innovation, including renewables, as a driver of rural revitalization
Renewable Energy Directive II/III	2018 / 2023	Promote citizen-led energy projects	Enables energy communities and cooperatives in rural regions to develop solar infrastructure

Source: Own survey based on (17)

The European Green Deal (10) is the main document at the centre of the transition, aiming for a climate-neutral EU by 2050 and focusing on clean energy as one of the central pillars. It is related to a strategic vision for integrating solar energy into decarbonisation and territorial cohesion goals.

In response to the energy security issues, the REPowerEU Plan was established in 2022. As an element, the EU Solar Energy Strategy sets ambitious targets of 600 GW solar photovoltaic capacity by 2030 (11). It also prioritises

agrivoltaics and community solar solutions to stimulate rural economies.

In addition, the Fit for 55 Package (18) presents energy targets, including a 42.5% share of renewables in final EU energy consumption by 2030. It strengthens the role of decentralised renewables such as rooftop solar and energy communities.

The Common Agricultural Policy 2023–2027 supports green transformation by funding projects related to renewable energy and energy efficiency (19). Solar installations on farms and

agrivoltaics are eligible for support. On that basis, the policy links agricultural modernisation with energy goals and stimulates farmers and rural communities to adopt solar technologies.

The EU Rural Vision for 2040 presents long-term prospects to revitalise rural areas by promoting infrastructure development, digital connectivity, and green solutions, including solar energy (20). In the strategic document, rural regions are seen as active participants in the energy transition and set a narrative for the future.

The Renewable Energy Directive (RED II and III) is the legal basis for renewable energy communities, which are particularly relevant in rural settings and can address energy poverty and boost social inclusion (13, 14).

These policy instruments form a framework to support rural solar energy. However, their implementation depends on how well Member States coordinate national plans and administrative processes and ensure access to financing. In this direction, concerns related to the synergies between policies remain. In addition, technical support, local capacity, and grid modernisation are key drivers to ensure these policies translate into practical solutions. The EU promotes a just and sustainable energy transition. One of the key opportunities in this direction is the concept of energy communities, which has gained policy attention across Europe since the 1990s. The regulatory framework supports the EU's climate and energy goals with the Revised Renewable Energy Directive (RED II – Directive (EU) 2018/2001). It promotes more active involvement of citizens, local authorities, and small and medium-sized enterprises in renewable energy generation through energy communities.

These communities can play a vital role in ensuring affordable and stable energy prices and improving energy security. In addition, they support local economic development by generating income, employment opportunities, and green jobs (21).

The number of energy communities in Europe has been rising and is linked to the growing importance of renewable energy initiatives. According to Koltunov et al (22), more than 4,000 renewable energy cooperatives exist across the EU, including around 900,000 members, mainly located in northwestern Europe. These initiatives vary significantly,

influenced by national regulations, institutional frameworks, and socio-economic conditions (23-25).

In Bulgaria, energy communities are gaining attention. Despite the relevance, they are constrained by unclear legal frameworks and limited institutional engagement at the national level. These gaps hinder the widespread establishment of the initiatives (26).

Regardless, several examples demonstrate the transformative prospect of energy communities in rural and urban areas.

The earliest initiative is "Izgrei BG", launched in 2022 in the village of Belozem, near Plovdiv. This project is notable for being Bulgaria's first energy community. It was initiated by three agricultural producers seeking to mitigate frequent power outages that directly affected the irrigation systems essential for their farming. The initiative ultimately adopted a limited liability company structure, which, while legally permissible, posed limitations on expanding membership (27).

A more structured and policy-aligned model has emerged in Gabrovo, where the "Energy Community Gabrovo – RDNO" was initiated by the municipality in collaboration with the Energy Efficiency Centre and with the support of international projects TANDEM and LIFELOOP. This community is based on a 100 kW PV installation at the Regional Non-Hazardous Waste Landfill site, funded at nearly BGN 160,000. The project enabled energy sharing among a network of 73 participants, including individual citizens, the municipality, and legal entities. Its success was recognised at the European level, including through inclusion in the EU's Energy Community Platform (28). Following the Gabrovo example, Burgas Municipality has launched an initiative to establish an energy community based on a 420 kWp rooftop PV system at the Park Arena sports complex. This project is similarly implemented under the TANDEM project and aims to use over 85% of the electricity produced for on-site consumption, with a total investment of BGN 431,802 (29).

Despite these encouraging initiatives, the energy communities in Bulgaria face several structural and policy-related challenges. They include the absence of a clear regulatory framework for energy sharing, limited economic incentives under the current system of energy prices, and insufficient protection

against discriminatory practices for small energy producers. (26, 30)

Different challenges, such as infrastructure, regulations, technical, financial, and socio-political factors, hinder the adoption and implementation of solar energy. A key barrier is associated with the existing energy infrastructure, particularly outdated and inflexible grid systems (31). Also, public engagement and social acceptance remain crucial elements of successful implementation. Some surveys suggest solar projects with local involvement and participatory governance structures are more likely to overcome resistance (32). In the political and regulatory context, policy landscapes and slow permitting procedures hinder solar energy projects (33). Further, the lack of skilled and educated professionals constrains the sector's expansion (34). Financial barriers associated with the high initial capital costs and policy instability often hinder investments (35). In addition, while solar energy improves energy diversification, it requires the integration of complementary technologies such as energy storage systems and demand-side management tools to maintain grid reliability and support broader energy security objectives (36).

In addition to the benefits, the balance between environment, biodiversity and land use should be considered.

CONCLUSIONS

Solar energy has considerable potential to address challenges in rural areas across the EU. As the IEA (37) emphasised, rural households generally face higher energy costs, making affordable and decentralised renewable energy solutions essential. For farmers, solar energy can provide income diversification. Integration of rooftop solar installations allows land use while lowering emissions through electrification and supporting transitions to sustainable agriculture (38).

Concerning social impacts, solar projects contribute to rural development by generating revenues through taxation and benefit-sharing mechanisms. This financial aid can support local infrastructure and services. Energy communities empower rural stakeholders and encourage local engagement with the energy transition (37, 38).

Meeting the fixed targets will generally depend on local governments' administrative and technical capacity. National support for legal

expertise and public engagement mechanisms is essential (38).

The rural areas have untapped potential for the development of solar energy. However, balancing solar projects with environmental and societal factors can add value to rural regions. To realise the full potential of solar energy in rural areas and avoid adverse environmental impacts, public engagement, effective land use planning and improved technical and administrative capacity are needed. Local authorities play a crucial role in supporting and promoting the development of solar projects and community initiatives.

REFERENCES

1. European Commission, EU rural areas in numbers. Luxembourg: Publications Office of the EU, 2021a.
2. European Environment Agency, Renewable energy in Europe – 2020: Recent growth and knock-on effects. EEA Report No. 11/2020.
3. Fragkos, P. and Siskos, P., Energy systems analysis and modelling towards decarbonisation. *Energies*, 15(6), p.1971, 2022.
4. International Renewable Energy Agency (IRENA), European Commission, Renewable energy prospects for the European Union, 2022. <https://www.irena.org>
5. Weselek, A. et al., Agrivoltaic systems: Applications, challenges, and opportunities. *Renewable and Sustainable Energy Reviews*, 141, p.110810, 2021. <https://doi.org/10.1016/j.rser.2021.110810>.
6. Barron-Gafford, G. A., Pavao-Zuckerman, M. A., Minor, R. L., Sutter, L. F., Barnett-Moreno, I., Blackett, D. T., & Thompson, M., Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. *Nature Sustainability*, 2, 848–855, 2019. <https://doi.org/10.1038/s41893-019-0364-5>
7. Roberts, J., What energy communities need from regulation. *European Energy & Climate Journal*, 8(3-4), pp.13-27, 2019.
8. European Commission, CAP explained: Rural development 2023–2027, 2023a. Available at: https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/rural-development_en [Accessed 10 Jul. 2025].
9. Perpiña Castillo, C. et al., Renewable energy production and potential in EU rural areas. Luxembourg: Publications Office of the

- European Union, 2024. doi:10.2760/458970.
10. European Commission, The European Green Deal. COM(2019) 640 final, 2019. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640> [Accessed 10 Jul. 2025].
 11. European Commission, REPowerEU Plan: Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2022) 230 final. Brussels: European Commission, 2022a. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0230> [Accessed 20 July 2025].
 12. European Commission, EU Solar Energy Strategy. COM(2022) 221 final, 2022b. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0221> [Accessed 10 Jul. 2025].
 13. European Union, Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources (RED II), 2018. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018L2001> [Accessed 10 Jul. 2025].
 14. European Union, Directive (EU) 2023/2413 on the promotion of the use of energy from renewable sources (RED III), 2023b. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023L2413> [Accessed 10 Jul. 2025].
 15. Eurostat Statistics Explained, Renewable energy statistics, 2024. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics [Accessed 10 Jul. 2025].
 16. Ember, Global Electricity Review 2024, 2025. Available at: <https://ember-energy.org/latest-insights/global-electricity-review-2025/> [Accessed 10 Jul. 2025].
 17. Wach, K., Głodowska, A., Maciejewski, M. and Sieja, M., Europeanization Processes of the EU Energy Policy in Visegrad Countries in the Years 2005–2018. *Energies*, 14(7), p.1802, 2021.
 18. European Commission, 'Fit for 55': Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality. COM(2021) 550 final, 2021b Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0550> [Accessed 10 Jul. 2025].
 19. European Commission, Regulation (EU) 2021/2115: Establishing rules on support for strategic plans under the CAP. Official Journal of the European Union, 2021c. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R2115> [Accessed 10 Jul. 2025].
 20. European Commission, A long-term Vision for the EU's Rural Areas – Towards stronger, connected, resilient and prosperous rural areas by 2040. COM(2021) 345 final, 2021d. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0345> [Accessed 10 Jul. 2025].
 21. Caramizaru, A. and Uihlein, A., Energy Communities: An overview of energy and social innovation. Luxembourg: Publications Office of the European Union, 2020.
 22. Koltunov, M. et al., Mapping of energy communities in Europe: status quo and review of existing classifications. *Sustainability*, 15, p.8201, 2023.
 23. European Network for Rural Development, Smart villages and renewable energy communities, 2020. Available at: https://ec.europa.eu/enrd/sites/default/files/enrd_publications/smart_villages-capacity_tools-renewable_energy_communities-v08.pdf [Accessed 11 Jul. 2025].
 24. REScoop, REScoop 20-20-20 – Best practices report II, 2014. Available at: <https://www.rescoop.eu> [Accessed 11 Jul. 2025].
 25. REScoop MECISE, Mobilising European Citizens to Invest in Sustainable Energy: Clean Energy for All Europeans. Final Results-Oriented Report of the RESCOOP MECISE Horizon 2020 Project, 2019.
 26. Spasova, D. and Braungardt, S., Building a common support framework in differing realities—conditions for renewable energy communities in Germany and Bulgaria. *Energies*, 14(15), p.4693, 2021.
 27. REScoop Europe, Pioneering community energy in Bulgaria. Available at: <https://www.rescoop.eu/news-and-events/stories/june-success-story-pioneering-community-energy-in-bulgaria> [Accessed 11 Jul. 2025], 2025.
 28. Obshtina Gabrovo, Gabrovo – inovatsii i ustoychivo razvitie. Available at: <https://gabrovo.bg/bg/article/21140> [Accessed 11 Jul. 2025], 2025.
 29. Obshtina Burgas, Energiyno byuro Burgas. Available at: <https://energy-office.bg/eo-burgas> [Accessed 11 Jul. 2025], 2025.

- LAVCHIEV S., et al.
30. Gancheva, L., Energy Cooperatives and Communities to Foster Social Innovation in the EU—a Bulgarian Case Study—Prospects and Barriers. *Proceedings of the International Conference on Business Excellence*, 18(1), pp.1453–1464, 2024.
 31. Obuseh, E., Eyenubo, J., Alele, J., Okpare, A. and Oghogho, I., A systematic review of barriers to renewable energy integration and adoption. *Journal of Asian Energy Studies*, 9, pp.26–45, 2025.
 32. Wolsink, M., Planning of renewable schemes: Deliberative and fair decision-making. *Energy Policy*, 35(5), pp.2685–2696., 2007. Mendonça, M., Jacobs, D. and Sovacool, B., 2009. *Powering the Green Economy*. London: Earthscan.
 33. IRENA, *Renewable Energy and Jobs – Annual Review 2021*. Abu Dhabi: International Renewable Energy Agency, 2021. Available at: <https://www.irena.org/publications/2021/Oct/ Renewable-Energy-and-Jobs-Annual-Review-2021> [Accessed 20 July 2025].
 34. REN21, *Renewables 2023 Global Status Report*. Paris: REN21 Secretariat. 2023. Available at: <https://www.ren21.net/reports/global-status-report/> [Accessed 20 July 2025]
 35. Lilliestam, J., Patt, A. and Bersalli, G., The effect of carbon pricing on technological change for full energy decarbonization: A review of empirical ex-post evidence. *Wiley Interdisciplinary Reviews: Climate Change*, 12(1), p.e681, 2021.
 36. International Energy Agency, *World energy outlook 2024*. Paris: International Energy Agency, 2024.
 37. SolarPower Europe, *Agrisolat Handbook*, 2024. Available at: <https://www.solarpowereurope.org> [Accessed 11 Jul. 2025].