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PARTICIPATORY GIS TOOL TO DEVELOP LAND-BASED SOLAR ENERGY SCENARIOS: THE EXAMPLE OF A BLACK FOREST DISTRICT IN GERMANY

Summary

The successful development of renewable energy requires the selection of suitable sites while respecting the objectives of nature conservation, agriculture and other stakeholders. To meet Germanys climate and energy y targets, the municipalities needs to balance renewable energy development with land use changes. The Public Participation Geographical Information System (PPGIS) scenario methodology helps to examine how land use decisions at local scale affect renewable energy potential, thereby assisting in this balance. This article uses a case study from the district of Emmendingen in the Black Forest (Germany) to show how the PPGIS scenario method can help rural communities and energy cooperatives integrate renewable energy transparently. The method takes into account land use restrictions and identifies areas that meet environmental, economic and social criteria. Different conflict-free land use scenarios are calculated for ground mounted and agricultural photovoltaics, estimating potential land demand and electricity generation.

Keywords: Public Participation Geo Information System (PPGIS), Scenario, Land demand, Energy yield, Energy Communities, Municipalities, Agri-Photovoltaics (Agri-PV), Ground mounted photovoltaic (GM-PV)

1. Introduction

Restructuring Germany's energy system is one of the greatest technical, economic, and social challenges of our time. Given global issues such as climate change and species extinction, transitioning from centralised, fossil fuel-based infrastructure to decentralised renewable energy generation seems to be the logical next step (Staab, 2018). Municipalities play a pivotal role in climate protection and the energy transition. For example, they are responsible for allocating land for wind and solar energy projects, and they are involved in the planning to decarbonise heat supply. This involvement is central to the energy transition. The key features of renewable electricity generation, such as ecology, decentralisation and the diversity of stakeholders, are currently being renegotiated at a municipal level. This has given rise to conflicting goals and implementation obstacles within individual stakeholder groups. The rapid expansion of renewable energies has placed considerable pressure on rural areas in a very short space of time, leading to new forms of competition for land and altering the cultural landscape (Bosch and Peyke, 2011). Local and regional conflicts of interest, such as disputes over competing land uses and renewable energy projects and facilities, could significantly impact the achievement of national energy transition targets. Several ground-mounted PV projects planned in recent years did not receive building permits due to strong local opposition and therefore could not be realized. The national scenarios demonstrate which technologies could be employed to transform the energy system at the lowest cost while achieving the greatest reduction in greenhouse gases (Wietschel *et al.*, 2010). However, they cannot simply be transferred to the municipal level in a top-down process. The natural, structural and socio-economic conditions for a decentralised energy infrastructure differ too greatly for this to be possible. Participatory local scenario development aims to bridge this gap by facilitating the practical implementation of national energy scenarios. Specifically, this involves reconciling the political framework conditions with local social and cultural needs. The 'openness of socio-technical options' premise is implemented through a dialogical process to improve procedural and distributive justice. Although social perspectives are recognised as promoting acceptance, they are often only superficially integrated, with more in-depth social and economic findings not being taken into account (Bosch and Schwarz, 2018). This work demonstrates how the development of local GIS scenarios can improve spatial planning accountability by increasing decision-making transparency. This provides municipalities with new possibilities for action. The PPGIS scenario method was applied to ground-mounted photovoltaic (GM-PV) systems and agrivoltaic systems (Agri-PV), enabling the simultaneous production of crops and generation of solar energy on the same land in the district of Emmendingen in the Black Forest region of Germany. The method and results are presented below.

2. Methods

The selection process for Agri-PV and GM-PV followed a structured approach to support informed decision making. The methodology integrates geospatial data on constraint criteria and builds on approaches used in previous studies by the authors (Fakharizadehshirazi and Rösch, 2024; Rösch and Fakharizadehshirazi, 2024, 2025). In this study, the potential for electricity generation from GM-PV and Agri-PV is assessed by first excluding constrained areas. These include areas within a 20 meters buffer zone around built-up areas, as well as areas intersecting with biodiversity and nature conservation zones, forests, non-permanent arable land (for Agri-PV), high quality arable land (for GM-PV), watercourses, water bodies, flood hazard zones and infrastructure with their safety zones. Arable land is divided into three crop groups: open arable land, permanent crops and permanent grassland. After excluding the restricted areas, GM-PV was considered for the remaining open arable land. Permanent crops (orchards and vineyards) were considered for horizontal Agri-PV, while permanent grassland (including natural meadows or pastures) was considered for vertical Agri-PV. Permanent grassland is assumed to consist of two landscape format bifacial modules mounted vertically in an east-west orientation. For horizontal Agri-PV, electricity production is calculated for both bifacial and monofacial modules.

3. Results

The potential area for GM-PV, as derived from the PPGIS modelling, is 238 ha. For Agri-PV, the potential area identified by the same modelling approach is 962 ha (permanent crops and permanent grasslands). This indicates that Agri-PV has a significantly larger potential area than GM-PV (Figure 1). Open arable land with GM-PV produces approximately 143 GWh of electricity per year. Permanent grassland with vertically mounted, east-west oriented bifacial agrivoltaic modules produces 65 GWh of electricity per year. For permanent crops (0.5% orchards and 99.5% vineyards), horizontal monofacial agrivoltaic systems produce 232 GWh of electricity per year, while the horizontal bifacial configuration increases this to 436 GWh per year (Figure 2). These results highlight the significant increase in electricity production made possible by bifacial module technology, especially in permanent crop systems.

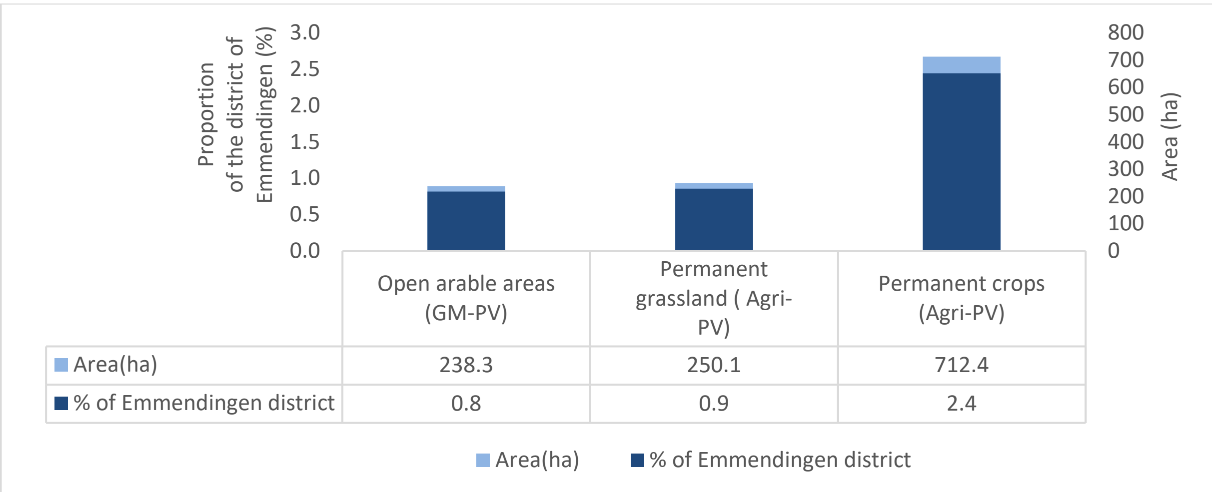

Figure 1: Potential demand for land suitable for Agri-PV and GM-PV as a percentage of the total agricultural area in the district of Emmendingen, Germany

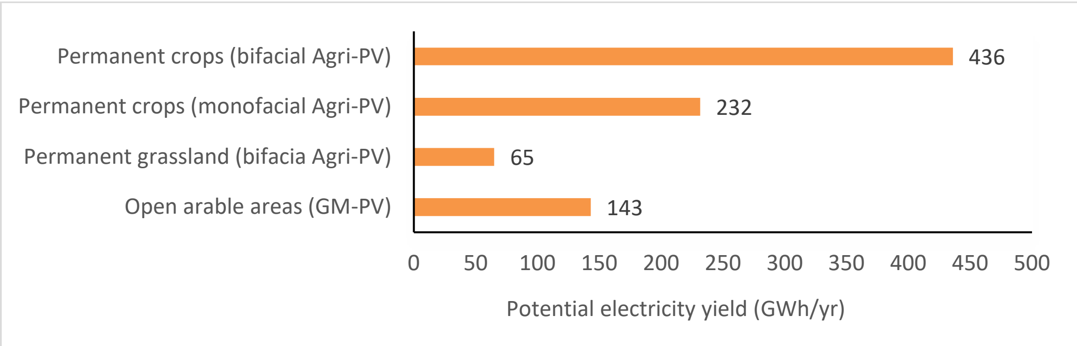

Figure 2: Potential electricity yield from Agri-PV and GM-PV areas in the district of Emmendingen (Germany) in GWh/yr

4. References

Bosch, S. and Peyke, G. (2011) ‘Gegenwind für die Erneuerbaren – Räumliche Neuorientierung der Wind-, Solar- und Bioenergie vor dem Hintergrund einer verringerten Akzeptanz sowie zunehmender Flächennutzungskonflikte im ländlichen Raum’, *Raumforschung und Raumordnung | Spatial Research and Planning*, 69(2), pp. 105–118. Available at: https://doi.org/10.1007/s13147-011-0082-6.

Bosch, S. and Schwarz, L. (2018) ‘Ein GIS-Planungstool für erneuerbare Energien–Integration sozialer Perspektiven’.

Fakharizadehshirazi, E. and Rösch, C. (2024) ‘A novel socio-techno-environmental GIS approach to assess the contribution of ground-mounted photovoltaics to achieve climate neutrality in Germany’, *Renewable Energy*, 227, p. 120117. Available at: https://doi.org/10.1016/j.renene.2024.120117.

Rösch, C. and Fakharizadehshirazi, E. (2024) ‘The spatial socio-technical potential of agrivoltaics in Germany’, *Renewable and Sustainable Energy Reviews*, 202, p. 114706. Available at: https://doi.org/10.1016/j.rser.2024.114706.

Rösch, C. and Fakharizadehshirazi, E. (2025) ‘Public participation GIS scenarios for decision-making on land-use requirements for renewable energy systems’, *Energy, Sustainability and Society*, 15(1), p. 18. Available at: https://doi.org/10.1186/s13705-025-00518-y.

Staab, J. (2018) ‘Zukunftsszenarien der dezentralen Energieversorgung, Ausblick: Auf dem Weg zur Postwachstumsökonomie’, *Erneuerbare Energien in Kommunen: Energiegenossenschaften gründen, führen und beraten*, pp. 229–242.

Wietschel, M. *et al.* (2010) *Energietechnologien 2050-Schwerpunkte für Forschung und Entwicklung*. Fraunhofer-Verlag.