Role-Differentiated Prioritization of Renewable-Energy Investments in Poland: Sector Targets, Technology Functions, and Municipal Effects

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Abstract: The transformation of Poland to the renewable energy economy requires the logic of technology-specific investment due to the differential pace of transformation in the sectors of electricity, heating, cooling, transport, and urban development. This paper offers a role-differentiated analysis of the paths of investment in renewable energy in Poland based on the sector policy goals, conditions of deployment of technologies, functions of system support and socio-economic effects at the municipal level. There are six paths analyzed: photovoltaic energy, wind power, biomass, biogas or biomethane, geothermal energy, and hydropower. The analysis relies on four dimensions: target relevance and scale, momentum of deployment and deployment feasibility, system integration value and socio-economic spillover at the municipal level. The results indicate that wind power and photovoltaic energy represent the first tier of expansion in view of the direct relation to 2030 transition targets in the electricity sector and the highest relevance of deployment at the national scale. Biomass and biogas/biomethane represent the second tier in terms of the value of the technology in decarbonization of the heat generation, flexible renewable production and valorization of resources. Geothermal energy and hydropower represent the selective relevance at the local level, where geological, hydrological and environmental conditions justify investments. Case study of Margonin wind farm proves that renewable energy projects may influence municipal revenues, landowner incomes, quality of the infrastructure, tourism, and business development.

Keywords: renewable energy; Poland; investment prioritization; wind power; photovoltaic energy; biomass; biogas; geothermal energy; hydropower; local development

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1. Introduction

The renewables transition in Poland is no longer a general issue about expanding renewable energy sources. The challenge in renewables' research in Poland is to prioritize investments when different renewable technologies serve different functions and penetrate different sectors. A fast-deployed photovoltaic power plant, a big-scale wind project which provides substantial electricity generation, a biogas facility which transforms agricultural and urban residues into energy, and a geothermal heat project with a connection to the local geological characteristics cannot be evaluated similarly. Therefore, the main question considered in this paper is the following: *Which renewable energy pathways should be prioritized in Poland when national decarbonization goals, feasibility of implementation, system services and effects on the municipality socioeconomics are taken into account?*

This is an essential question since Poland starts the transition from historically coal-intensive energy system. Thus, the transition is associated not only with climate change mitigation but also with ensuring energy affordability, security of supply, coal region restructuration, energy grid modernization, and old fossil-fuel energy asset replacement [1,2]. The European climate policy increases pressure to accelerate the decarbonization process, while the energy price and supply shocks in the beginning of 2020s make energy security an integral part of investment plans [3]. Therefore, for Poland, the investment in renewables is a strategic allocation problem, i.e., the money should be invested in technologies which can decrease emissions and support the system reliability.

Another complication is that the policy framework in renewables is not determined by a single goal. The National Energy and Climate Plan, the Energy Policy of Poland till 2040, and later policy considerations include such elements as the share of renewable energy sources, electricity generation, heat and cooling, transportation, electricity grid capacity and storage, prosumers development, and offshore wind [4]. Such sectoral structure is significant, since the technology, which can effectively expand the electricity generation, can be useless for increasing renewable heat. Moreover, a small-scale technology can be important due to its ability to provide dispatchable generation or rural resource flow. Thus, the analysis should go beyond a simplistic ordering on the basis of installed capacity [5].

Literature on energy transitions supports such an approach. Energy transitions are path-dependent, institutionally driven and uneven across sectors; technologies spread through the combination of cost reduction, regulation, infrastructure availability, public acceptance and proper market design rather than technological potential [6]. Moreover, the assessment of renewable energy is supposed to take into account distribution of benefits and costs. Studies on social acceptance and regional sustainability confirm that such factors as local income, land payments, improvements of infrastructure and community engagement can significantly influence the sustainability of renewable energy deployment [7].

The Polish renewable energy literature increasingly acknowledges these complications. Photovoltaics' growth is analyzed considering the impact of prosumer incentives, falling prices, and regulation predictability [8]. The literature on wind energy development stresses the role of siting and permitting, offshore potential, and local acceptance [9]. Biogas, biomass, and hydropower are considered taking into account sector-specific limitations, such as feedstock logistics, heat demand, wastes management, environmental permitting, and hydrological restrictions [10]. The works provide interesting insights at the technology level, but do not always develop them into the investment-ordering logic.

This paper addresses this gap by providing a role-based prioritization approach for Poland. It does not aim to make market share forecasts or optimization of least-cost power system. However, it builds the evidence in a transparent decision structure which distinguishes primary expansion technologies, functional technologies and selectively locality-related technologies. Such an approach is helpful for both policy and investments as it connects the national transition timeline with the functions, which the particular renewables can serve.

2. Background in Literature

The international literature on the transition to renewable energies has progressed from an abstract endorsement of low-carbon technologies into a concern with specific issues of coordination, flexibility, and institutional sequencing. The earlier literature considered renewable energy in the framework of climate change mitigation, learning, and policy support; later works made clear that high-renewables systems require complementary assets, network investment, storage, demand-side response, and market reform [11]. In terms of Poland, it means that expansion technologies should not be analyzed independently from the networks, balancing measures, and end-user sectors that will have to accommodate their output.

The second strand of literature considers social acceptance and local development. Renewable-energy facilities are commonly opposed in case people feel that the benefits go elsewhere while costs are local. On the contrary, social acceptance is achieved in case projects contribute to municipal budgets with revenues from taxes, leases, roads, jobs, security of supply, and business activities [12]. This literature is particularly important for wind energy since large facilities have pronounced physical visibility and can redefine local economies.

The third literature strand includes technology-specific problems in Poland. Photovoltaics have advantages in terms of short construction time, modularity, and involvement of households. However, fast development poses problems related to capacity of the distribution grid and managing midday surpluses. Wind energy provides large amounts of electric power and the opportunity for offshore development. However, the rate of development depends on permits, grid access, supply chains, and social acceptance. Biomass and biogas can provide dispatching or heat functions, but their sustainability depends on feedstock quality, impact on land use, and logistics. Geothermal and hydroelectricity have a geographic limitation but offer stable local services under favourable natural conditions [13].

The strategic problem is that all three aspects are usually addressed separately. Policy documents set goals; studies of particular technologies focus on certain energy sources; social sciences consider acceptance and benefits. Priority setting requires integrating these perspectives. The current paper aims at filling the gap by addressing questions about priorities of expansion technologies, system functions, and place-specific developments.

3. Materials and Methodology

The paper relies on a qualitative-comparative assessment that is based on policy papers, public reports, and academic literature. Six renewable-energy technologies are analyzed: photovoltaic energy, wind power, biomass, biogas and biomethane, geothermal energy, and hydropower. The data source includes the renewable-energy targets in Poland's energy-sector plans, reported capacity increase, conditions of implementation of each specific technology, and observed socio-economic impacts in Margonin wind-farm example.

Four criteria of assessment are used. Alignment with the 2030 transition priorities and scale of technology, which are represented by letter A, reflects the extent of contribution to the key challenges of the 2030 transition. Momentum and feasibility of implementation of technology, represented by letter M, includes observed diffusion, construction cycle time, difficulty of permitting, financing condition, and infrastructure readiness. System integration value, represented by letter S, reflects the contribution to flexibility, controllability, thermal decarbonization, balancing, and operation compatible with storage. Finally, local socio-economic spillovers, represented by letter L, reflect observed impacts on municipalities and territories beyond energy production.

The priority score for technology i is expressed as follows:

$$P_i = 0.30A_i + 0.25M_i + 0.25S_i + 0.20L_i. \tag{1}$$

In the priority score expression above (Eq. (1)), the largest weight is assigned to the alignment criterion because a technology that cannot contribute to the 2030 transition should not be a dominant force of the country's energy-investment strategy. The weights of feasibility and system integration value are equal because the fast development of a technologically useless option and useful implementation without momentum are not enough. The smallest weight, but still quite large, is given to the local spillover because it creates a positive impact on municipalities and thus increases legitimacy and sustainability of the solution.

Table 1. Assessment dimensions.

Symbol	Dimension	Meaning in the assessment
A	Target alignment and scale	Contribution to the main 2030 renewable-energy trajectory and to sectors where expansion pressure is strongest.
M	Deployment momentum and feasibility	Present implementation speed, regulatory viability, construction lead time, financing practicality, and infrastructure access.
S	System-integration value	Capacity to support flexibility, dispatchability, heat supply, balancing, storage interaction, or resource valorization.
L	Local socio-economic spillover	Municipal revenue, land income, infrastructure improvement, employment, tourism, business attractiveness, or other place-based gains.

The dimensions listed in Table 1 make it clear that the methodology does not reduce the transition process to one engineering metric. It is quite possible for the same technology to be good for one dimension and poor for the other. That is crucial for Poland, as the problem of investment relates to role allocation, not selection of dominant renewable resource.

4. Poland's Setting of Renewable-Energy Transition

Poland's setting of renewable-energy transition is characterized by sectoral asymmetry. Electricity generation is clearly the most obvious domain of renewable acceleration, whereas heating, cooling and transport sectors require different types of interventions. Sectoral values used in the paper show that the target for power sector is clearly larger than for transport, with gross final energy target lying between these two extremes. Such target configuration demonstrates that expansion of renewable electricity is necessary, but not enough for full transition.

Sector target profile in Figure 1 illustrates that power sector has the largest near term renewable share in the policy trajectory assessed in this paper. Heating and cooling represent another major area of transition, while transport sector stays the hardest one. Visual analysis of target configuration confirms the paper's main hypothesis: Poland's renewable energy strategy should differentiate between technologies expanding renewable electricity and those dealing with heat, fuels and flexibility.

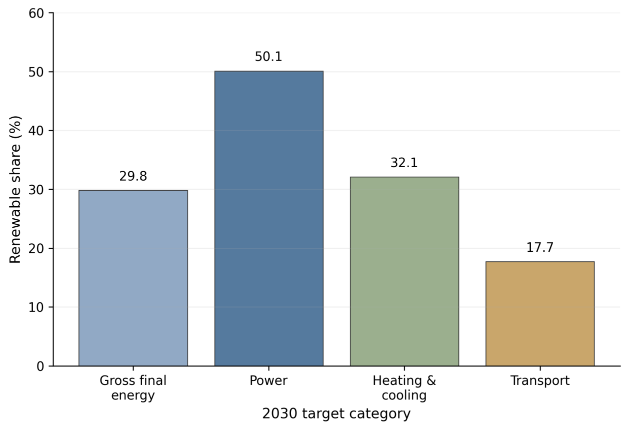

Figure 1. 2030 sector targets.

Rate of growth of recent renewable capacity installed in Poland is also significant for investments prioritization. Installed renewable capacity increased from 7.1 GW in 2015 to 28.8 GW in 2023, demonstrating that Poland has shifted from limited renewable penetration level to much more active investment setting.

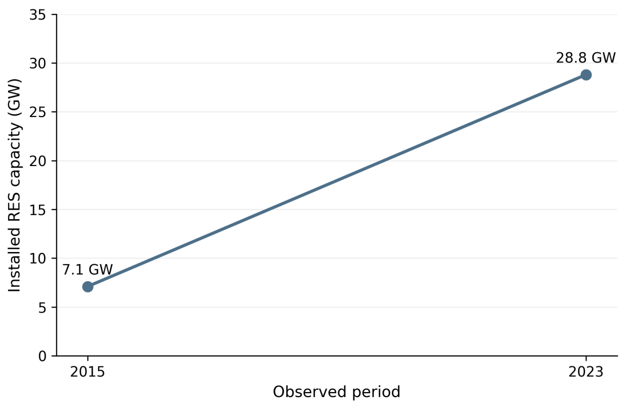

Figure 2. Installed RES growth.

Capacity growth in Figure 2 should not be seen as guarantee that all renewable technologies will keep growing at similar rate. On the contrary, it illustrates the fact that Poland currently has a practical renewable energy investment basis. Next step of the policy would be ordering of technologies in accordance with their role, restrictions and system value.

5. Results and Discussion

5.1. Technology Roles and Priority Scores

The role-oriented assessment results in the creation of three different tiers of technologies. Wind energy and photovoltaics make the primary tier of technologies for national-scale development. The reason behind the superiority of these technologies is their direct relation to decarbonization in the electricity sector, significant output, and fit with the 2030 transition timeline. The high priority score of wind energy is explained by its scaling capacity, positive spillovers and system-related effects, while its development can be hindered by permitting and site issues. Photovoltaics are comparable to wind power in terms of strategic value due to its fast deployment and implementation cycles, despite the increasing need for grid reinforcement and energy storage facilities.

Biogas, biomethane and biomass belong to the second tier and represent the functional-support technologies. What makes them strategic in relation to other sources of electricity production is that they provide additional functions, which are difficult to supply by intermittent renewables. Biogas and biomethane are strategic because they utilize organic waste streams, allow for controlled generation, and connect the energy policy with waste management and agriculture. Biomass generation is still valuable for heating and industrial or district energy purposes, as long as sustainability requirements are met.

Geothermal energy and hydropower constitute the third tier. They have a potential to play a certain role in the generation mix when conditions are favourable, however, they cannot become engines for national-scale development at the current Polish situation. Geothermal energy has a great potential only where there is a combination of heating needs and geological conditions. Hydropower generation can provide balancing and generation services.

Table 2. Role-based technology scores.

Technology	A	M	S	L	P_i	Strategic role
Wind power	5	4	4	5	4.50	Primary national expansion technology with strong electricity contribution and visible municipal spillover, subject to permitting and grid constraints.
Photovoltaic energy	5	5	3	3	4.10	Rapid modular expansion technology with high deployment momentum; system value rises with storage, grid reinforcement, and flexible demand.
Biogas/biomethane	3	2	5	4	3.45	Controllable support pathway linking renewable energy with waste management, agriculture, flexibility, and gas-system substitution.
Biomass	3	3	4	3	3.25	Thermal and resource-based support option, strongest in heat applications where feedstock sustainability can be verified.
Geothermal energy	2	2	4	2	2.50	Local heat option with stable output but limited geographical scalability.
Hydropower	2	1	4	2	2.25	Supplementary balancing and local generation source constrained by hydrology and environmental permitting.

The prioritization matrix in Table 2 provides an answer to the research question from an operational perspective. Poland needs to avoid equal distribution of investment attention across different renewable technologies. Expansion of wind and photovoltaic electricity should get the top priority, whereas biogas, biomethane, and biomass need to be prioritized for their thermal and flexibility purposes in particular. Geothermal energy and hydropower require localization-based opportunities screening instead of assumption about their national-scale potential.

The hierarchical ranked score profile depicted in Figure 3 does not mean that lower-ranked technologies are of no worth. The gap in score ratings between the first two technologies and all others shows that they have the national-scale character, and the mid-level shows that controllable and thermal technologies are still required for the balanced transition process. It means that any realistic investment strategy should combine the fast growth in electricity generation with those technologies, which will compensate for deficiencies of variable generation sources.

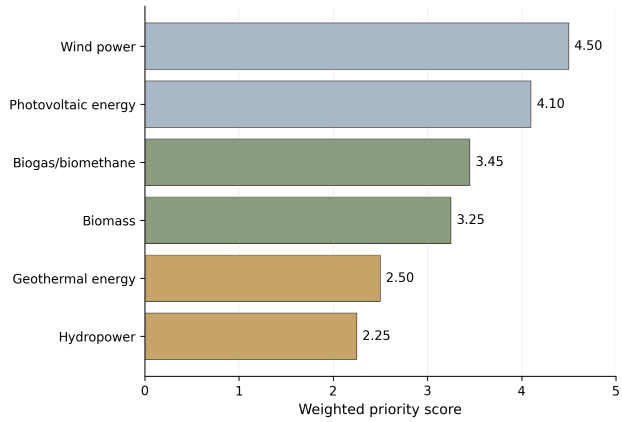

Figure 3. Technology priority scores.

5.2. Dimension-Level Interpretation

Dimension-level scores reveal that the simple ranking of technology according to their installed capacity will be misleading. Photovoltaic energy demonstrates a good result in both target alignment and feasibility dimensions but gets low marks in system integration due to the network problems in case of uncontrolled solar energy expansion. Wind power has good results in almost all dimensions except for the one concerning site restrictions. Biogas and biomethane get bad marks in deployment momentum but good results in system integration, which makes them interesting in spite of low national-scale potential. Biomass, geothermal, and hydropower have special places in the hierarchy.

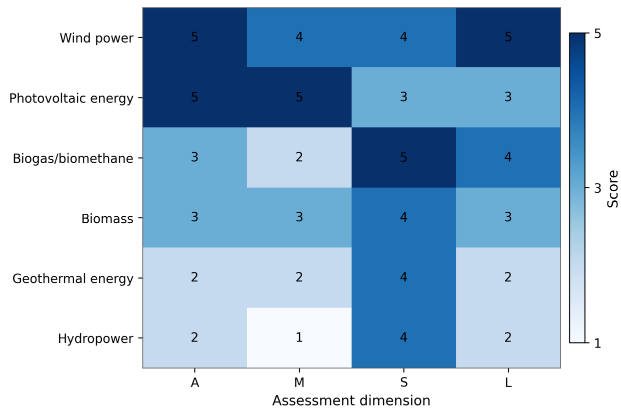

Figure 4. Dimension-level scores.

It can be concluded from the dimension profile presented in Figure 4 that the investment preferences in Poland are contingent upon the dimension. High A and M values for photovoltaic energy show the importance of speed and scale dimensions. High values of S in the cases of biogas, biomass, geothermal energy, and hydropower refer to the dimension of operational usefulness. Finally, the high value of L in the wind power example suggests the local income and territorial effects' significance. The distinctions between the investments prove that portfolio approach should be used instead of undifferentiated renewable energy goal.

5.3. Local Socio-Economic Spillovers: The Margonin Example

The Margonin case study shows how important local socio-economic spillovers are for assessment. It involves electricity production for about 243 thousand people, reduction of more than 65 thousand tons of CO_2, 10% increase in commune income, additional PLN 8,000 annually for those who have leases of land, construction of additional 10 km of local roads, positive effects on tourism, and local business attractiveness [14]. The results above cannot substitute the assessment of the energy system but change its significance.

As seen from Table 3, the Margonin effects of the project under consideration make clear that the case study is not just a renewable-energy generation example. What makes this project strategically relevant is the combination of energy production, emissions reductions, fiscal impacts, increased household income, infrastructure development, and regional economic positioning. Such a combination provides an explanation for the relatively high local spillover score of wind power in the prioritization matrix.

Table 3. Margonin project effects.

Area	Reported effect	Interpretation for investment strategy
Energy supply	Electricity for about 243 thousand inhabitants	Large wind projects can connect national electricity goals with visible regional supply capacity.
Climate effect	More than 65 thousand tons of CO_2 avoided	Emissions benefits strengthen the climate rationale but should be considered alongside local effects.
Municipal finance	10% increase in commune income	Fiscal gains can improve local acceptance and give municipalities resources for public services.
Land income	About PLN 8,000 per year per leaseholder or landowner	Direct payments distribute part of the project benefit to local households and land users.
Infrastructure	About 10 km of local roads improved	Construction and access requirements can leave durable local infrastructure gains.
Local economy	Tourism and business attractiveness improved	Renewable projects can contribute to place visibility and secondary economic activity.

Figure 5 depicts the Margonin profile of the project effects. Instead of a schematic map, the indicators are arranged in the form of a numeric profile, because they are measured in different units. The figure shows that the evaluation of renewable-energy projects should consider their various impacts instead of focusing on electricity production only.

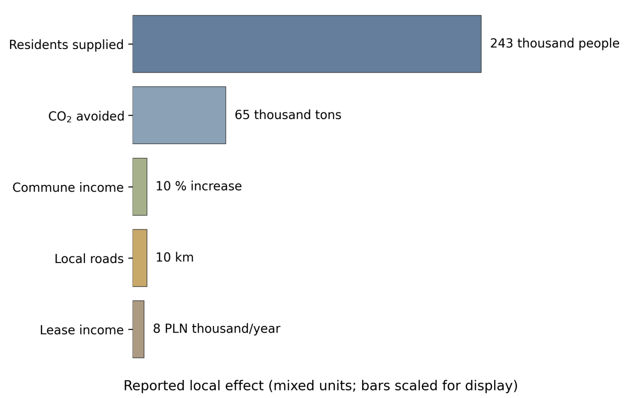

Figure 5. Margonin local effects.

5.4. Policy Synthesis

Three elements of a comprehensive investment strategy are suggested by the findings. First, Poland should concentrate on wind power and photovoltaics as expansion technologies at a national scale. Such a strategy will require further permitting reforms, stable auctions or support mechanisms if necessary, grid reinforcement and energy storage deployment, as well as market regulations that would reward flexibility. Second, Poland should promote biomass, biogas, and biomethane for the purposes which would make the system of high renewable-energy penetration more robust: heating decarbonization, controllability of energy output, use of organic residues, and sector coupling. Third, Poland should invest in geothermal energy and hydropower if and where resource potential, environmental assessment, and local demand justify.

Figure 6 depicts the profile of the investment order of the technologies. It is worth saying that the suggestion that Poland should avoid lower-ranked technologies is not implied here. Rather, such ranking means that different policy instruments should be used for primary, support, and selective technologies.

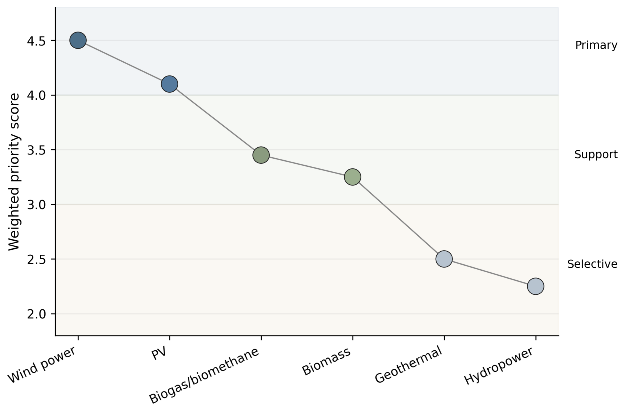

Figure 6. Investment order.

Such a synthesis makes the problem of transport sector clear. The relatively small share of renewables in transport sector can hardly be resolved by mere electricity generation. It requires electrification of the sector and infrastructure for it, renewable fuels, biomethane, hydrogen where appropriate, investments into public transport and demand-side policies. In other words, the renewable-energy investment strategy should be coupled with end-use policy.

6. Conclusion

This paper asked which renewable-energy technologies should be prioritized in Poland, given their sectoral relevance, deployment feasibility, added value to the electricity system, and socio-economic impacts on the local community. The answer is varied. Wind energy and photovoltaics should occupy the first place in terms of investments since they demonstrate the highest linkage with the electricity-sector transition process and national-level relevance in the context of the 2030 transition process. Wind energy will be highly relevant in areas with appropriate permitting process, grid connection opportunities, and local benefit arrangements. Photovoltaics will be relevant due to their modularity, fast installation time, and proven deployment dynamics.

Biomass, biogas, and biomethane must not be viewed as competitors to wind and solar technologies, whose development was hindered by the former two. They should occupy the place of functional support, such as decarbonization of heat energy production, renewable energy control, organic residue use and conversion into useful products, and flexibility of the electricity system.

Geothermal energy and hydropower should also stay in the portfolio; however, they will be used selectively, based on local geological and environmental conditions. The Margonin example proves that renewable-energy investment can have a strategic effect on the local communities through altering their energy balances, income, economic development, road infrastructure, tourism industry, and other factors.

The main conclusion drawn from the analysis presented in this paper is that Poland needs a role-based renewable-energy portfolio, not a technology preference, and not just a renewable-energy target without differentiation. Priority should be given to technologies depending on the function they fulfill during the transition: wind and photovoltaics for scale, biomass and biogas/biomethane for heat generation and flexibility, and geothermal energy and hydropower for local-level support.

Data Availability Statement

This study is based on policy documents, public reports, and scholarly literature cited in the reference list.

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