Summary

The doctoral dissertation addressed the critical challenge of assessing the potential utilization of infrastructure and resources from decommissioned hard coal mines for economic purposes following the cessation of underground mining activities. The research was conducted within the broader context of Poland's planned decarbonization by 2050, aligning with the European Union's climate and energy policies. Particular emphasis was placed on minimizing the socio-economic impacts of mine closures on local communities, with a focus on developing sustainable business models grounded in the principles of a circular economy.

The scientific objective of the study was to create a method for evaluating scenarios that repurpose mining assets in alignment with renewable energy production and storage. The practical aim was defined as identifying opportunities for the integration of these scenarios into broader economic frameworks, ensuring compliance with EU regulations and promoting regional development.

A systematic methodology was developed, starting with the identification of key criteria for assessing the potential of closed mines. These criteria included local conditions, the availability of resources, and the feasibility of repurposing mining infrastructure. A criteria-driven analysis provided a foundation for categorizing scenarios into "actions" and "micro-actions," facilitating a structured approach to scenario evaluation and prioritization.

The restructuring of the coal mining sector in Western Europe served as a reference point, highlighting successful and unsuccessful strategies in transitioning from coal-based industries. The near-complete cessation of hard coal mining in these countries was accompanied by efforts to diversify regional economies, create alternative employment opportunities, and implement energy transitions. In contrast, the restructuring of Poland's hard coal sector over the past 35 years was characterized primarily by mine closures, reductions in production, and social support programs. The limited reuse of mining resources in Poland underscored their untapped potential for economic and environmental transformation.

In the study, scenarios for repurposing decommissioned mines were developed and analyzed. These scenarios varied in complexity, ranging from standalone business models to complementary components within broader economic frameworks. The division into "actions" and "micro-actions" facilitated a detailed examination of each scenario's technological, economic, and environmental implications.

Morphological analyses revealed significant synergies between key actions and micro-actions. The "Eco-Industrial Park" and "Virtual Power Plant" actions were identified as strongly interconnected and were recommended for integration into a unified business model. This

model could be further enhanced by the inclusion of hydrogen production facilities, which demonstrated high technological readiness levels (TRL) and alignment with EU taxonomy requirements. Among the micro-actions, "Geothermal Energy" and "Gravitational Energy Production" were identified as complementary, sharing technological characteristics and offering significant potential for integration within a single business model.

The proposed scenarios were evaluated through multi-criteria analyses grounded in the principles of the European Green Deal. The analysis considered factors such as climate change mitigation, economic growth, and social equity. The highest-ranked scenarios included the "Eco-Industrial Park," "Virtual Power Plant," and "Geothermal Energy" micro-action, reflecting their capacity to address energy transition goals while contributing to regional economic development.

The optimal business model identified in the study was a synergistic integration of an eco-industrial park and a virtual power plant. This model was designed to repurpose decommissioned mining sites into hubs for renewable energy production and storage. Key features of this model included the use of geothermal energy from mine waters, photovoltaic panels, and wind energy, combined with advanced energy storage systems. The incorporation of hydrogen production facilities further enhanced the model's potential, offering opportunities for integration into broader energy networks.

The study highlighted the versatility of the developed method, which can be adapted to other types of mining facilities, including those extracting metals, sulfur, or salt, as well as decommissioned fossil fuel power plants. However, it was emphasized that specific adjustments would be required to account for local conditions and resource availability.

The research also examined the forecasted lifespan of active Polish coal mines, identifying significant challenges associated with natural hazards and resource constraints. Mines with extensive resource bases often faced severe geological risks, limiting the feasibility of long-term operations. Conversely, mines with fewer natural hazards were found to lack sufficient resources for prolonged exploitation without significant financial investment. These findings underscored the necessity of transitioning from coal-based activities to alternative economic models that leverage existing infrastructure and resources.

The method developed in the dissertation was validated through interdisciplinary expert consultations, involving representatives from research institutions, mining oversight authorities, and industry stakeholders. Specialized analytical tools were employed to ensure the robustness and reliability of the findings. The results demonstrated the method's effectiveness in evaluating the potential of closed mines for repurposing and in supporting decision-making processes for regional transformation.

The findings emphasize the importance of integrating economic, technological, and environmental considerations into the planning and implementation of post-mining transformations. The proposed business model aligns with the principles of a circular economy, promoting resource efficiency, waste reduction, and sustainable energy production. By fostering collaboration among stakeholders, the model aims to facilitate an equitable and sustainable transition for post-mining regions.

In conclusion, the study provides a comprehensive framework for assessing the potential of decommissioned coal mines to contribute to energy and economic transitions. The proposed solutions offer practical pathways for achieving the dual goals of decarbonization and regional development, ensuring a just transition for affected communities. Further research was recommended to refine and expand the application of the method, with particular attention to economic feasibility and long-term sustainability.