Decarbonization cost transfer mechanism in the net-zero economy: Korean case study

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Overview

Achieving net-zero emissions has emerged as a global priority, necessitating ambitious energy transition and electrification policies across multiple sectors (Wiseman, 2018). The electrification of the transport sector, specifically through the adoption of battery electric vehicles (BEVs), has been highlighted as a key strategy for reducing greenhouse gas (GHG) emissions. However, the integration of BEVs introduces cross-sectoral challenges, as increased electricity demand shifts decarbonization costs to the power generation sector.

In South Korea, this issue is particularly pressing due to the country's unique constraints: limited land availability for renewable energy expansion, a heavy reliance on carbon-intensive industries, and an isolated electricity grid (Cho and Yim, 2020). This study evaluates the economic and environmental impacts of BEV dissemination on South Korea's power sector, focusing on cost transfers and the implications for achieving the 2030 Nationally Determined Contribution (NDC) target.

This study aims to three targets. First, we attempt to quantify the economic and environmental costs associated with BEV dissemination. Second, we examine the implications of alternative energy mixes on electricity system stability and cost-effectiveness. Finally, this study will provide policy recommendations for managing cross-sectoral decarbonization costs while maintaining progress toward net-zero goals.

Methods

To assess the impact of BEV dissemination, this study employs a scenario-based analysis integrated with electricity system modeling. The scenarios were designed to reflect varying energy policy directions and levels of renewable energy and nuclear power utilization:

- **Baseline (BS):** No additional BEV-related electricity demand, maintaining the current policy to phase out both nuclear and coal power.
- **BEV1:** Incorporates the deployment of 3 million BEVs, as outlined in South Korea's Fourth Basic Plan for Eco-Friendly Vehicles (2021–2025), under the same nuclear and coal phase-out policy.
- **BEV2:** Continues nuclear power operation at an 80% capacity factor while phasing out coal power.
- **BEV3:** Maximizes nuclear capacity at 85%, reflecting an increased emphasis on nuclear utilization.
- **Extreme:** Combines the continued use of nuclear power (85% capacity) with a 30% share of renewable energy in power generation, exceeding the targets of the 10th Basic Plan for Long-Term Electricity Supply and Demand (BPLE).

The PLEXOS electricity market simulation software was used to model the hourly electricity demand and generation profiles for 2030, incorporating BEV charging patterns derived from behavioral simulations (Deane et al., 2012). Transition costs were analyzed based on (Foley et al., 2013):

1. **Electricity System Costs:** Calculated as the product of the system marginal price (SMP) and total electricity generation.
2. **Environmental Costs:** Measured as the social cost of GHG emissions, estimated at $51 per metric ton of CO_2 equivalent (IWG, 2021).

Results

The analysis reveals significant economic and environmental impacts resulting from the dissemination of BEVs under varying scenarios. In the BEV1 scenario, where 3 million BEVs are deployed while maintaining the phase-out of both nuclear and coal power, the electricity system costs increase substantially, driven by the reliance on liquefied natural gas (LNG) to meet the heightened electricity demand. This leads to a system marginal price increase and imposes a financial burden on the power sector. Additionally, the reliance on fossil fuels results in a significant rise in greenhouse gas emissions, further exacerbating environmental costs.

In contrast, scenarios that involve continued nuclear power operation demonstrate notable cost and emission reductions. For instance, the BEV2 scenario, which assumes an 80% nuclear capacity factor, effectively mitigates some of the cost increases observed in BEV1. This mitigation becomes even more pronounced in the BEV3 scenario, where maximizing nuclear utilization at an 85% capacity factor substantially reduces both economic and environmental costs. However, these improvements alone are insufficient to meet South Korea's 2030 NDC target.

The Extreme scenario, which combines an 85% nuclear capacity factor with a 30% renewable energy share, achieves the most favorable outcomes. This scenario not only minimizes system costs but also brings greenhouse gas emissions close to the 2030 NDC target. The integration of renewable energy, alongside nuclear power, proves essential in reducing the reliance on LNG and achieving a more sustainable energy mix. Despite these positive outcomes, the Extreme scenario highlights challenges related to renewable energy integration, such as grid flexibility and increased operational complexities.

Conclusions

This study provides valuable insights into the economic and environmental costs associated with the electrification of the transport sector, focusing on the cost transfers to the power sector. The findings emphasize that achieving net-zero emissions requires an integrated approach that considers the interconnected nature of energy policies across sectors.

While BEV dissemination offers significant environmental benefits for the transport sector, it simultaneously imposes financial and environmental costs on the power sector. The results highlight the importance of utilizing nuclear power as a transitional measure to manage these costs effectively. However, reliance on nuclear power should be viewed as a short-term solution, with a long-term focus on expanding renewable energy deployment and enhancing grid flexibility.

Policymakers should adopt strategies that balance economic and environmental goals, including incentivizing renewable energy, improving grid flexibility, and developing robust greenhouse gas monitoring systems. These efforts will not only support South Korea's progress toward its 2030 NDC target but also provide a blueprint for other nations facing similar energy transition challenges. By addressing the cross-sectoral impacts of electrification, this study contributes to a more comprehensive understanding of the pathways to a sustainable and cost-effective energy future.

References

Cho S, Yim M. Examining the feasibility of nuclear-renewable hybrid energy system in Korea: a case-based analysis of high penetrations of solar energy. Int J Energy Res 2020;44:8133–43.

Deane JP, Chiodi A, Gargiulo M, Bp´o Gallach´oir. Soft-linking of a power systems model to an energy systems model. Energy 2012;42:303–12.

Foley A, Tyther B, Calnan P, B´o Gallach´oir. Impacts of electric vehicle charging under electricity market operations. Appl Energy 2013;101:93–102.

Interagency Collaboration. The 4th basic plan for eco-friendly vehicle in Korea (2021~2025). 2021.

Interagency Collaboration. 2030 Intended nationally determined contributions of Korea. 2021.

IWG. Technical Support Document. Social cost of carbon, methane, and nitrous oxide interim estimates under executive order 13990. 2021.

Wiseman J. The great energy transition of the 21st century: the 2050 Zero-Carbon World Oration. Energy Res Social Sci 2018;35:227–32.