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OVERALL ASSESSMENT

I have examined Lukas Recka's PhD Thesis entitled "Three Essays in Energy and Environmental Economics". The thesis comprises of three substantive papers. My overall assessment is as follows:

a) Can you recognize an original contribution of the author? **YES**
b) Is the thesis based on relevant references? **YES**
c) Is the thesis defendable at your home institution or another respected institution where you gave lectures? **YES**
d) Do the results of the thesis allow their publication in a respected economic journal? **YES**
e) Are there any additional major comments on what should be improved? **NO**
f) What is your overall assessment of the thesis? (A) I recommend the thesis for defense without substantial changes, (B) the thesis can be defended after revision indicated in my comments, (C) not-defendable in this form. **A**

The thesis may be accepted as it is. I elaborate on the above points below, chapter by chapter. Otherwise I would like to congratulate the candidate for convincingly responding to earlier suggestions and producing an excellent thesis.

Paper 1: LMDI Decomposition of Air Pollutants in the Czech Republic between 1990 and 2016: sensitivity analysis of LMDI parameters

The first paper uses the REZZO database compiled by the Czech Hydro-Meteorological Institute and the Supply and Use Tables compiled by the Czech Statistical Office to conduct a rigorous analysis of the main driving forces of air pollution reduction from the 1990s to 2016. The Logarithmic Mean Divisia Index decomposition is used to statistically decompose the annual changes in SO2, NOx, CO and PM emissions from eight categories of fuel [(1) brown coal, (2) biomass, (3) biogas, (4) hard coal, (5) natural gas, (6) oil, (7) other gases and (8) other solids] into (i) the scale effect, (ii) the composition effect, (iii) the energy-intensity effect, (iv) the fuel-mix effect, and (v) the fuel-intensity effect.

The paper finds that the most prominent driver of the emission reductions in the Czech economy was the emission content of fuels used in economic production. This mainly came from the end-of-pipe technologies installed in response to command-and-control regulations of the 1990s. As both the fuel-mix and fuel-intensity factors did not contribute much to emission abatement, the regulations did not bring about any modernisation in technology.

The paper makes a contribution by using the 5-factor decomposition as opposed to the traditional 3-factor decomposition, where the latter approach typically merges the last three factors into a single intensity effect. As emission coefficients have been time invariant in previous studies, the 5-factor decomposition enriches literature due to a richer variation calculated based on time variant chemical and technological parameters across facilities and time. Furthermore, there is only a few applications of a decomposition analysis in Central and Eastern European countries hence this study contributes to filling an important gap in literature.

Paper 2: Impacts of reclassified brown coal reserves on the energy system and deep decarbonisation target in the Czech Republic

The second paper builds a more robust energy system model, TIMES, to describe the Czech energy system with more precision and assess how it is impacted upon by energy policies. While previous work has used similar models to analyse the impacts of (i) carbon pricing, (ii) brown coal availability, and (iii) the price of natural gas, the substantive work in this paper uses the TIMES model to analyse the impacts of maintaining the ban on mining coal reserves on the Czech energy system. The rationale of focusing on the ban is that a 24-year long prohibition of coal mining within some territories in the North Bohemia coal basin was lifted and, as a consequence, mining the brown coal reserves there might well be resumed. The ban is compared with three alternative scenarios that each make this ban less environmentally stringent: (i) lifting the brown coal mining limits at the Bílina open pit, (ii) partial lifting of the mining limits on the second open pit (ČSA), and (iii) completely abandoning the mining limits on the second open pit (ČSA). The impacts of each of these alternatives on the fuel- and technology-mix, the costs of generating energy, related emissions and external costs associated with the emissions up to 2050 are analysed.

The paper finds that the overall effect of lifting the ban on coal usage, air pollution and external costs is up to 1–2% compared to the level of keeping the ban. The environmental and external health costs attributable to emissions of local air pollutants stemming from power generation are in a range of €26–32 billion over the whole period and decline from about 0.5% of gross domestic product in 2015 to 0.1% in 2050. The impacts of the three proposed policy options do not differ much from the impacts involved by pre-2015 policy that would keep the ban up to 2050. The results withstand a variety of sensitivity tests with respect to the prices of fossil fuels, European Emission Allowances price and deployment of nuclear power technology. The bottom line finding is that the currently adopted policy options will not help achieve the European Energy Roadmap 2050 targets and perform far worse than the ban, which would itself fail to meet the targets.

The modelling effort in this paper improves upon previous models such as MESSAGE on electricity and a partial TIMES version on the power sector. This paper extends the TIMES model structure with respect to usage of detailed operational data and linking technology operation to emissions and the damage they cause. It also addresses uncertainty by two means, covering both its sources. The TIMES model in this paper is updated to account for 2012 individual- and sector-level data and the base year is calibrated according to the Eurostat energy balance. The TIMES model covers the entire energy balance of the Czech Republic from primary energy sources to final energy consumption. The paper has great relevance in its reaction to the 2015 governmental decision to lift brown coal mining limits in North Bohemia. The results are academically enlightening and, as a consequence, have already received good reception in academic community as evidenced by the publication of this paper in an energy journal with a good impact factor.

Paper 3: Influence of renewable energy sources on transmission networks in Central Europe

The third paper expands its geographical focus to Central Europe. This paper investigates a contradiction between two important energy policy directions of EU: on one side creating a

unified energy market, on the other side promoting renewable energy, where the problems with accommodation of renewable electricity in electricity transmission networks provide strong policy incentives to close the national networks and to refuse the transfer of electricity from other countries during high-production events. Specifically, the paper analyses the impact of the massive increase in wind and solar installations in Germany (under the planned transition policy to a low carbon, environmentally sound, reliable, and affordable energy supply, *Energiewende*) on transmission networks in Central Europe. The German Energiewende policy together with insufficient transmission capacity between northern and southern Germany as well as the existence of the German-Austrian bidding zone heavily contribute to congestion in the Central European transmission system.

The paper specifically builds and uses the non-linear optimization model ELMOD, which maximizes social welfare under a number of constraints, for the impact assessment. The paper analyses the impacts of increased renewable energy feed-in and nuclear phase-out on cross-border grid congestion in Central Europe and on volatility growth in transmission networks in Central Europe. Two development scenarios for the year 2025 are evaluated on the basis of four representative weeks. The first scenario focuses on the effect of Energiewende on the transmission networks. The second scenario drops out nuclear phase-out and thus assesses the isolated effect of increased feed-in of renewable energy.

The results indicate that higher feed-in of solar and wind power increases the exchange balance and total transport of electricity between transmission system operator areas as well as the average load of lines and volatility of flows. Solar power is identified as a key contributor to the increase in volatility while wind power is identified as a key contributor to the loop-flow. The paper concludes that German nuclear phase-out does not significantly exacerbate mentioned problems.

Unlike many other papers, this paper makes an important contribution by focusing on the whole of Central Europe in the same detail as Germany and particularly elaborates on the influence of individual components of the German *Energiewende* policy (i.e. renewable energy promotion and nuclear phase-out) on the whole area. The paper also stresses the importance of the German - Austrian bidding zone which was mostly neglected in the previous research. This paper uses a "critical scenario approach" meaning that the results must be interpreted in the context of what would be the impact of electricity flows on the grid if nothing was changed in grid development. This is a unique paper focusing on the loop-flows in the Central Europe. The novelty of the paper is further evidenced by its acceptance at a top journal such as Energy Policy.

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