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Cross-country electricity trade, renewable energy and European transmission infrastructure policy

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ABSTRACT

This paper develops a multi-country multi-sector general equilibrium model, integrating high-frequency electricity dispatch and trade decisions, to study the effects of electricity transmission infrastructure (TI) expansion and renewable energy (RE) penetration in Europe for gains from trade and carbon dioxide emissions in the power sector. TI can benefit or degrade environmental outcomes, depending on RE penetration: it complements emissions abatement by mitigating dispatch problems associated with volatile and spatially dispersed RE but also promotes higher average generation from low-cost coal if RE production is too low. Against the backdrop of European decarbonization and planned TI expansion, we find that emissions increase for current and targeted year-2020 levels of RE production and decrease for year-2030 targets. Enhanced TI yields sizeable gains from trade that depend positively on RE penetration, without creating large adverse impacts on regional equity.

For several reasons, promoting cross-country electricity trade and transmission infrastructure is a major European policy issue. Electricity produced from fossil fuels generates environmental externalities.[1] Achieving sizeable emission cuts as envisaged under European Union's (EU) climate policy will require that large amounts of electricity are produced from intermittent renewable energy (RE) sources such as wind and solar. As these RE sources are not evenly distributed across Europe, with wind resources predominantly located on the periphery of the continent and often far away from demand centers, it seems unlikely that climate policy targets can be achieved without complementary cross-country transmission infrastructure policy (TIP). By sharing more efficiently "back-up" production capacities across countries, electricity trade can moreover help to reduce the costs of integrating large amounts of intermittent RE sources into today's economies and to increase security of energy supply. In addition, cross-country electricity trade increases competition with benefits for consumers. While these arguments provide a rationale for public policy oriented toward promoting cross-country electricity trade, surprisingly little is known about the interactions between transmission infrastructure, renewable energy, and environmental outcomes.

This paper develops a multi-country multi-sector general equilibrium framework, integrating high-frequency electricity dispatch and trade decisions, to study the effects of transmission infrastructure expansion and renewable energy

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[1] In 2014, approximately 40% of European carbon dioxide (CO_2) emissions—the principal anthropogenically sourced "greenhouse gas" contributing to global climate change—derived from electricity use (International Energy Agency, 2015).

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penetration in Europe for the regional distribution of gains from trade and CO_2 emissions from electricity production. Combining a general equilibrium model with a bottom-up electricity dispatch model permits a consistent welfare analysis while being able to approximate determinants for cross-country electricity trade and ensuing gains (or losses) from trade, also taking into account the use of electricity in the broader economic system. Besides cross-country differences in technology and production costs, hourly electricity trade is driven by imperfectly correlated demand and supply across countries while being constrained by cross-border transmission infrastructure. The trade effects are included in a fully specified numerical general equilibrium model for Europe that is calibrated using empirical country-level data on hourly electricity demand, installed generation capacities, hourly RE (wind and solar) production, and social accounting matrix data on production, consumption, and bi-lateral trade (in non-electricity commodities).

Our analysis highlights the central role played by infrastructure for environmental outcomes. On the one hand, electricity grid infrastructure might complement emissions abatement by mitigating dispatch problems associated with renewables. On the other hand, enhanced transmission infrastructure might promote higher average generation using low-cost base-load fossil (e.g., coal) with relatively higher emissions intensity—therefore degrading, rather than benefitting, environmental outcomes. How transmission infrastructure impacts emissions may further depend on contemporaneous renewable energy policy affecting the amount of low-cost renewables which can be more effectively distributed in an enhanced electricity grid.

While this fundamental trade-off arguably arises in most interconnected energy systems that are sufficiently large and geographically dispersed, we examine this issue in the context of European decarbonization and electricity transmission infrastructure policy. Recently, analysts and policymakers have called for new and more comprehensive policies to increase cross-border transmission capacities for electricity in Europe. The Ten Year Network Development Plan (TYNDP) is the main instrument under current EU regulation aimed at extending cross-border TI. The TYNDP, administered and implemented by the European Network of Transmission System Operators for Electricity (ENTSO-E), identifies transmission expansion plans deemed necessary to ensure that the future TI facilitates achieving EU energy and climate policy goals (ENTSO-E, 2014).[2]

Our analysis shows that at low levels of renewables in line with current and year-2020 EU targets, infrastructure enhancement induces a substitution toward low-cost coal-fired electricity yielding higher emissions (at the European level). At higher levels of renewables, in line with 2030 EU targets, infrastructure enhancement lowers emissions, because spatial variations in RE production can be better dispatched to meet demand. An important implication of our analysis is that "environmentally friendly" but spatially uncoordinated RE policies in a highly developed grid bear the risk of unintended consequences in the form of degraded environmental outcomes and emissions leakage. While the problem is only transient and will eventually disappear once the RE penetration is sufficiently large, our findings point to the need to consider a coordinated emissions and infrastructure policy.

Another important finding is that enhanced transmission infrastructure has the potential to bring about sizeable gains from trade through increased economic efficiency. Depending on the level of RE production, the TYNDP would yield aggregate (Europe-wide) gains between 1.6 and 2.6 billion 2011$ per year (corresponding to an 0.02–0.03% increase in annual welfare which is non-negligible given that the value share of electricity in total output is only about 4%). Infrastructure enhancements beyond the TYNDP could deliver gains between 5.8 and 8.7 billion 2011$ per year, corresponding to an 0.06–0.09% increase in annual welfare. Notably, we find that welfare gains from TI enhancements significantly increase with the level of RE production as low-cost renewables can be more efficiently distributed in an enhanced electricity grid. Welfare gains from the TYNDP are about twice as large for year-2030 RE levels, as targeted by EU climate policy as what would obtain for current (year-2012) levels.

Notably, we do not find strong adverse equity impacts from enhanced TI in terms of the regional distribution of gains from electricity trade. TI enhancement makes the large majority of countries better off. Some countries with initially low electricity prices or "wheeling" (electricity transit) countries experience slight welfare losses from enhanced European cross-border TI. Losses arise primarily due to losses in non-electricity sectors of the economy, underscoring the importance of an economy-wide perspective beyond just electricity. Lastly, we show that enhanced TI profoundly changes the pattern of regional CO_2 emissions.

Our paper is related to the literature in several ways. Assessing the environmental and economic impacts of enhanced TI is intimately linked to understanding what drives cross-country electricity trade. Electricity is a homogeneous good that can only be stored at high cost, and output may be produced by a wide range of different technologies. Demand and supply conditions vary considerably over both short time scales of a day and longer time scales of a season or year. Two-way trade in a homogeneous good (electricity) in our model is a result of aggregation over time similar to Antweiler (2014). von der Fehr and Sandsbraten (1997) present a stylized theoretical partial equilibrium model to investigate the gains from liberalizing electricity trade in the Nordic countries. Our set-up differs from Antweiler (2014) and von der Fehr and Sandsbraten (1997) in that it integrates two-way trade in a general equilibrium framework.

It is important to understand both the determinants of transport costs and the magnitude of the barriers to trade that they create. Previous trade literature has shown (Gramlich, 1994; Bougheasa et al., 1999; Limao and Venables, 2001) that

[2] The TYNDP includes so-called "Projects of Common Interest", that is, electricity projects with significant benefits for at least two member states. The majority of planned TI projects are expected to be commissioned by 2030, and the ENTSO-E (2014) expects that by promoting international electricity trade and by enabling the integration of large amount of RE sources the planned TIP will bring about significant economic and environmental gains in terms of reduced cost of electricity for consumers, increased profits for electricity firms, and a reduction of electric-sector CO_2 emissions.