Cross-Country Electricity Trade, Renewable Energy and Transmission Infrastructure Policy

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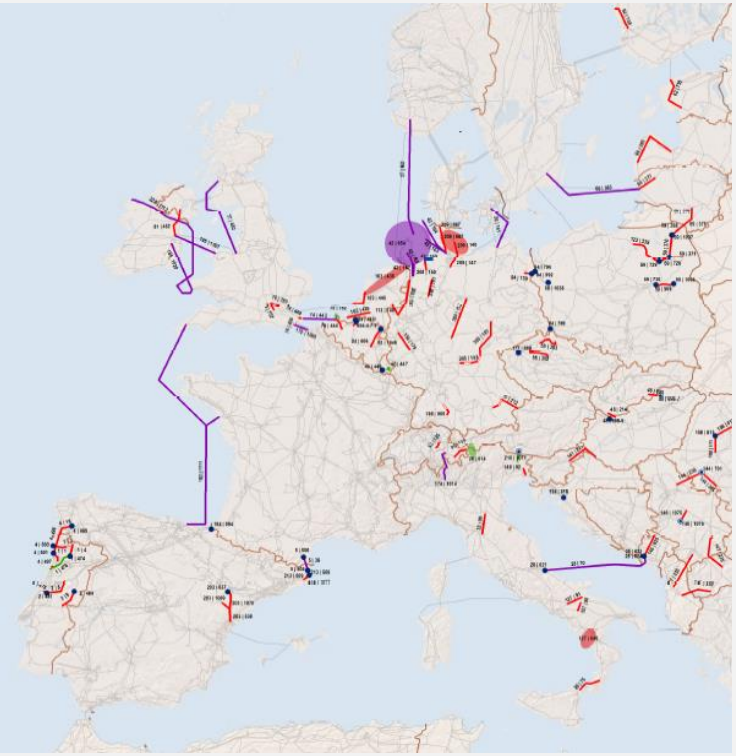
Outline

1. Motivation
2. Methodology
4. Cross-Border Trade and Renewable Energy
5. Summary

Motivation

- Why are cross-country electricity trade and transmission infrastructure policy (TIP) important? In particular in light of increasing deployment of renewable energy sources (RES)?
  - Addressing climate change: enable expected major shift in generation pattern due to increase in RES
  - Security of supply, intermittency and backup problem
  - Improving competition through market integration



- Planned European cross-border electricity TIP?

  ➔ Ten Year Network Development plan (TYNDP) contains transmission expansion plans identified as necessary to ensure that transmission grid facilitates EU energy policy goals

Main questions

1. What is the effect of electricity grid expansion (Ten Year Network Development Plan, TYNDP), on aggregate and regional welfare in Europe?

2. What is the interaction between grid and renewable energy expansion?

Methodology/model

3. How can relevant determinants of cross-country electricity trade be adequately represented within a macro-economic framework

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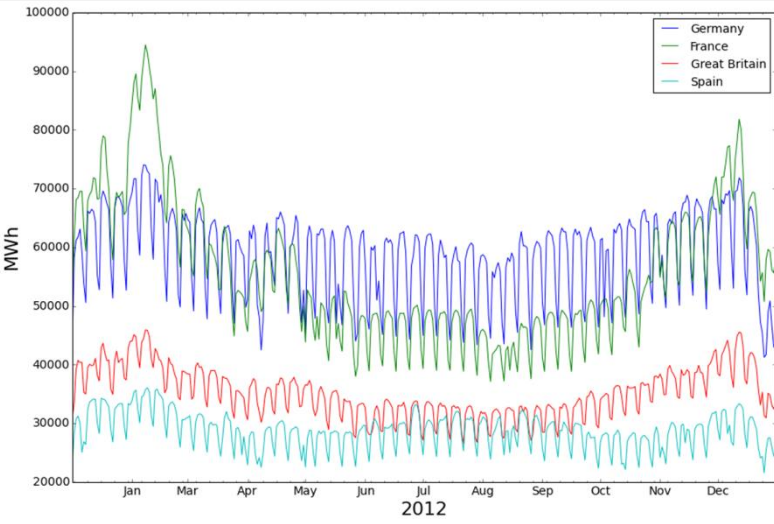
Methodical Motivation

- Electricity is a homogenous commodity
- Bilateral trade flows vary within a day and across seasons
- Bilateral trade restricted by transmission capacities



➔ Bilateral trade in homogenous commodity with physical constraint

➔ Existing trade approaches are of limited use

Development of electricity model with high temporal resolution and transmission constraints

Linking to macro-economic model

Simulation model: overview

“Top-down” general equilibrium model

- CGE model for Europe benchmarked to observed socio-economic data (GTAP8)
- Country-level detail for Europe (same 18 countries as in electricity model)
- Sectoral detail
  - Energy sectors: coal, gas, crude, and refined oil
  - Non-energy sectors: energy-intensive industries, agriculture, services, manufacturing, transportation)
- Bi-lateral trade flows (for non-electricity goods) based on Armington approach

Model countries

“Bottom-up” electricity model

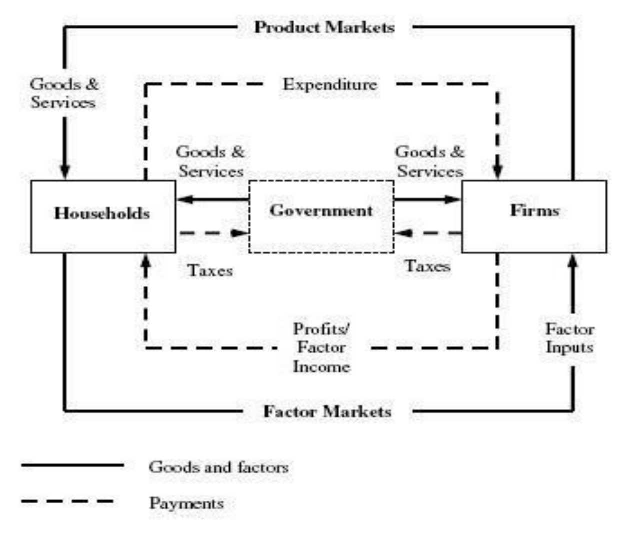
- Electricity generation dispatch model for Europe
- One year with hourly resolution (8760 hours)
- Conventional generation (restricted by installed and exogenously given capacity)
- Exogenous renewable energy production
- Storage facilities restricted by reservoir, generation and pump capacity
- Cross-border flows restricted by exogenously given net transfer capacities (NTC)
- Power plant flexibility restricted by ramping cost (dynamic cost curves)

Models are linked using decomposition algorithm

Macro-economic model: Summary

- Macro-economic **computable general equilibrium model** for Europe calibrated and benchmarked to observed socio-economic data (GTAP)

- **Main model features:**
  - Country-level detail for Europe (same 18 countries as in electricity model)
  - Sectoral detail:
    - **Energy sectors**: coal, gas, crude, and refined oil
    - **Non-energy sectors**: energy-intensive industries, agriculture, services, manufacturing, transportation)
  - Bi-lateral trade flows (for non-electricity goods)



General equilibrium macro-model based on economic theory

- Cost-minimizing consumer and producer behavior
- Markets are cleared for commodities and factors
- Price-dependent market interactions
- Origination and spending of income

Electricity Dispatch Model

Minimize total system costs

$$COST := \sum_{t\in\mathcal{T},p\in\mathcal{P}} G_{pt}\left[\sum_{f\in\mathcal{M}_p^F,c\in\mathcal{M}_p^C}\left(\frac{pf_{cf}+\theta_f pc_c}{\eta_p}\right)\right]$$

$$\sum_{t\in\mathcal{T},p\in\mathcal{P}} G^+_{pt}\left[cr_p^D + cr_p^F \sum_{f\in\mathcal{M}_p^F,c\in\mathcal{M}_p^C}\left(\frac{pf_{cf}+\theta_f pc_c}{\eta_p}\right)\right]$$

subject to following constraints

$$\sum_{p\in\mathcal{M}_c^C} G_{pt} + \sum_{s\in\mathcal{M}_c^C}(V_{st}-W_{st})$$

$$+\sum_{\tilde{c}\in C}[(1-\gamma)T_{\tilde{c}ct} - T_{c\tilde{c}t}] = d_{ct} \boxed{-\sum_{r} ren_{rt}}$$

$$\sum_{p\in\mathcal{M}^{PC},p\in\mathcal{M}^{R}} R^+_{pt} \geq d^{R+}_{ct}$$

$$\sum_{p\in\mathcal{M}^{PC},p\in\mathcal{M}^{R}} R^-_{pt} \geq d^{R-}_{ct}$$

Markets for electricity and reserve capacity are cleared

$$G_{pt} \geq R^-_{pt} \qquad \alpha_{pt} cap^G_p \geq G_{pt} + R^+_{pt} \quad \forall p,t$$

Generation capacity constraint

$$G^+_{pt} \geq G_{pt} - G_{p(t-1)} \qquad G^+_{pt} \geq l_p cap^G_p$$

Ramping restrictions

$$cap^V_s \geq V_{st} \qquad cap^L_s \geq L_{st}$$

$$L_{s(t-1)} + \eta_s W_{st} - V_{st} = L_{st} \qquad cap^W_s \geq W_{st}$$

Storage

$$\boxed{ntc_{c\tilde{c}}} \geq T_{c\tilde{c}t}$$

Cross-country trade restrictions

Computational Strategy

“Hard-link” of two models achieved using decomposition algorithm (Böhringer & Rutherford, JEDC 2009)

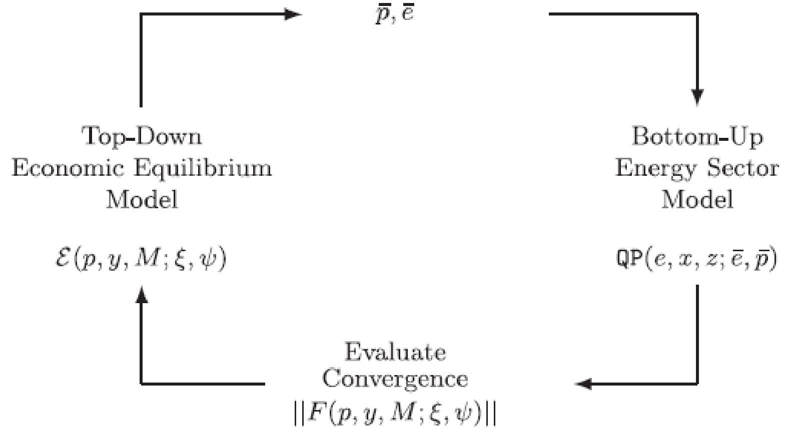


Fig. 1. Iterative decomposition algorithm.

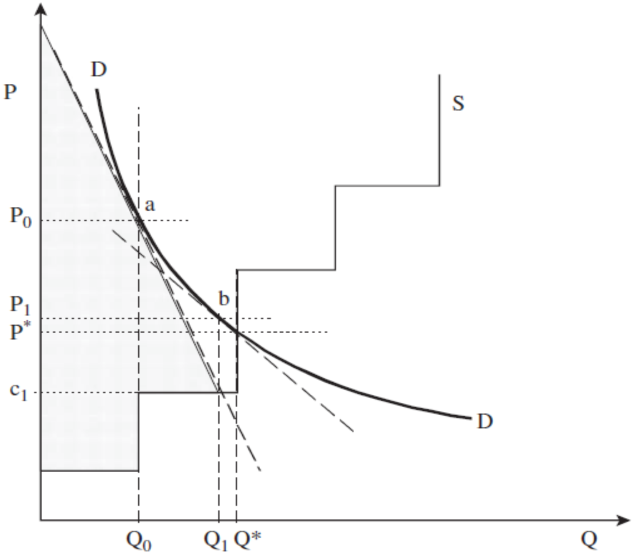


Fig. 2. Iterative adjustments: single market partial equilibrium.

Objective function of BU electricity model modified to maximize social surplus (producer + consumers surplus) over all regions (given demand functions)

Assumptions:

Consumers react to yearly average prices

Hourly profiles remain unchanged and are scaled with yearly demand

Integrated TD-BU model solves for general equilibrium prices and quantities

Figures 1 and 2 are taken from Böhringer & Rutherford (JEDC, 2009).

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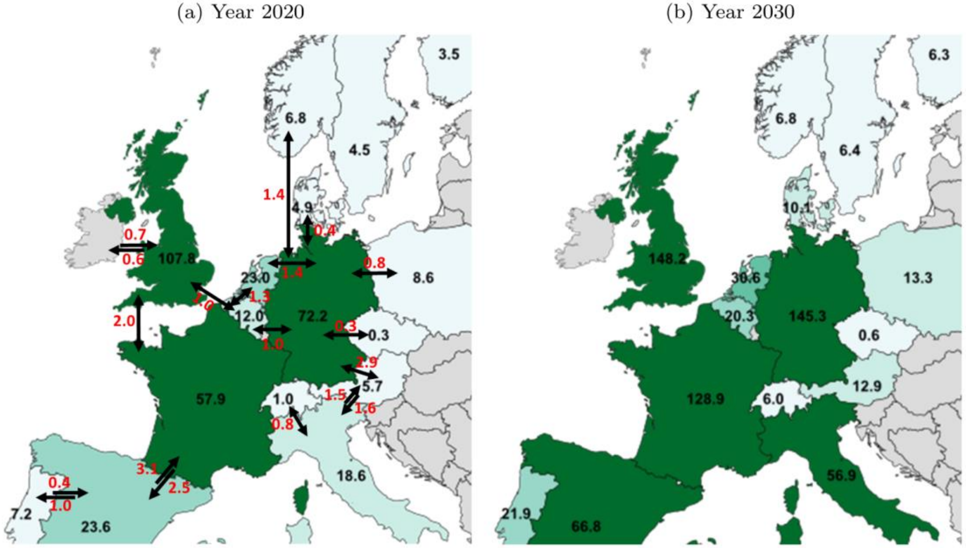
Scenario Setup

- Transmission capacities:
  - *a)* *Current*: NTCs of 2012
  - *b)* *TYNDP*: Increased according to Ten Year Network Development Plan (midterm)
  - *c)* *Full integration*: Unlimited capacity

Figure 9. Increases in cross-border transmission capacities (red, GW) and annual renewable electricity production for wind and solar (black, TWh) underlying the simulation dynamics



Note: Assumed increases in cross-border transmission capacities for 2030 are identical to those for 2020 and are hence not shown in Panel (b). Not shown is also an additional transmission extension of 700 GW at the border between Belgium and Luxembourg.

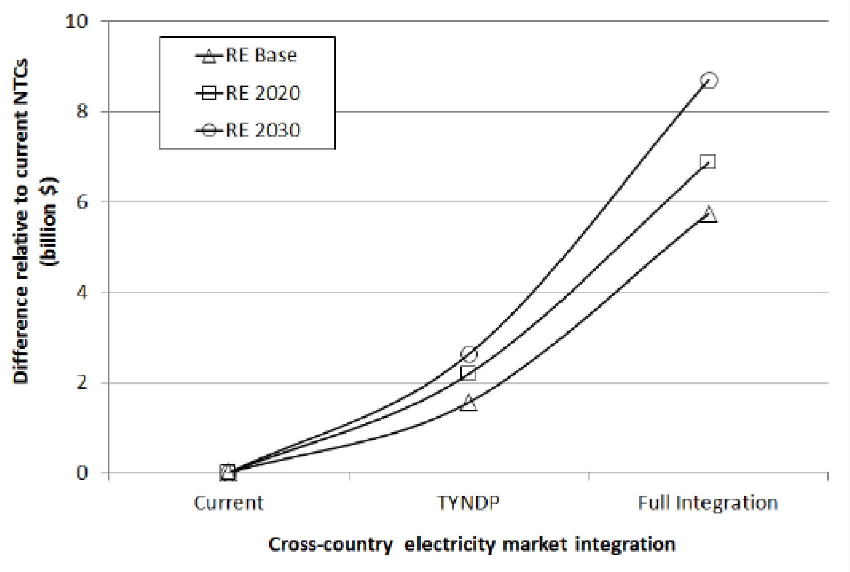
- Renewable Generation
  - *a)* *RE Base*: 2012 values
  - *b)* *RE 2020*: 2020 values
  - *c)* *RE 2030*: 2030 values

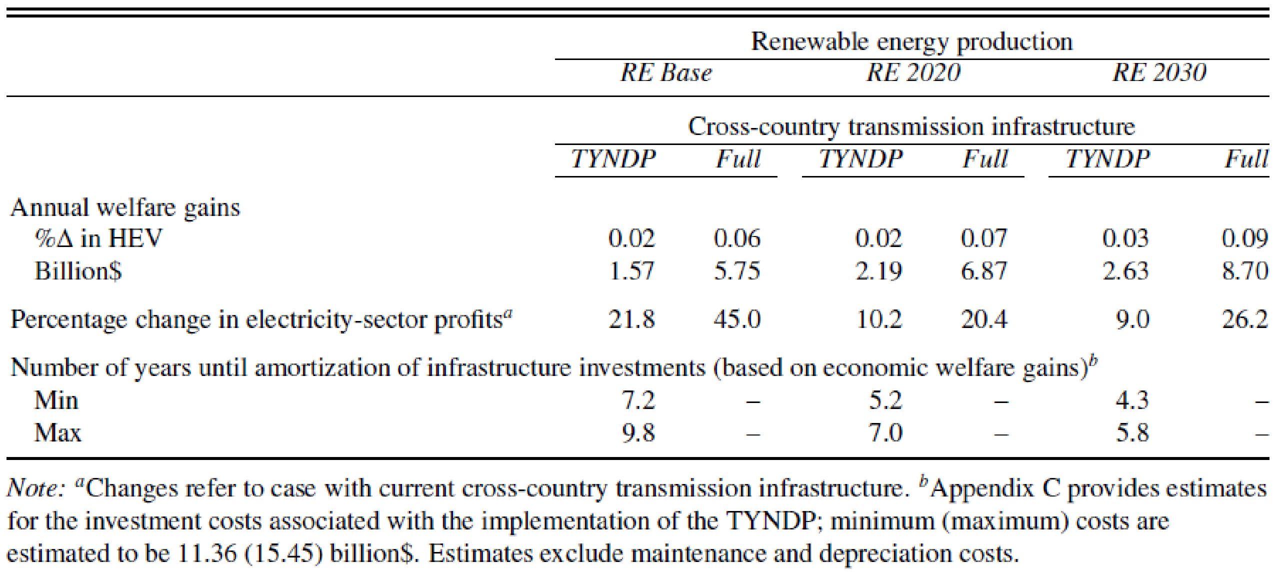
Scenario assumptions based on:

- Renewables: EU Energy, Transport and GHG Emissions Trends to 2050, Reference Scenario 2013
- NTC extensions and investment costs: Ten Year Network Development Plan (ENTSOE, 2014)

European Welfare Impact

- Welfare gains of grid expansion increasing in level of renewables
- Relative short pay-back time for TYNDP





	Renewable energy production					
	RE Base		*RE 2020*		*RE 2030*	
	Cross-country transmission infrastructure					
	TYNDP	*Full*	*TYNDP*	*Full*	*TYNDP*	*Full*
Annual welfare gains						
%Δ in HEV	0.02	0.06	0.02	0.07	0.03	0.09
Billion$	1.57	5.75	2.19	6.87	2.63	8.70
Percentage change in electricity-sector profits[a]	21.8	45.0	10.2	20.4	9.0	26.2
Number of years until amortization of infrastructure investments (based on economic welfare gains)[b]						
Min	7.2	–	5.2	–	4.3	–
Max	9.8	–	7.0	–	5.8	–

Note: [a]Changes refer to case with current cross-country transmission infrastructure. [b]Appendix C provides estimates for the investment costs associated with the implementation of the TYNDP; minimum (maximum) costs are estimated to be 11.36 (15.45) billion$. Estimates exclude maintenance and depreciation costs.

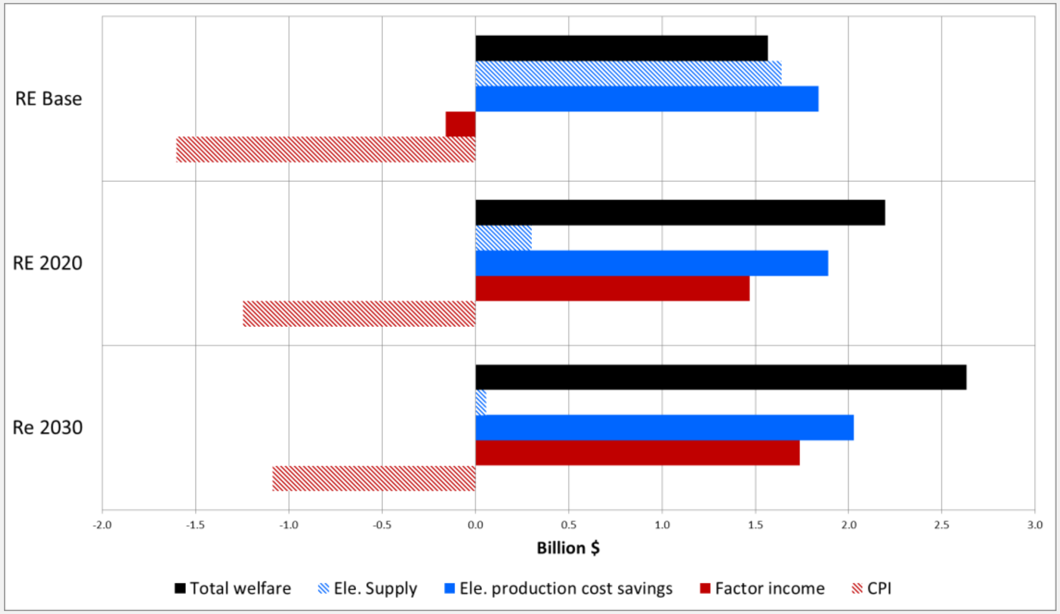
Welfare Decomposition (TYNDP)

Welfare effects are decomposed in electricity sector and macroeconomic effects

Electricity Sector:

(1) Change in value electricity supply

(2) Change in electricity production cost



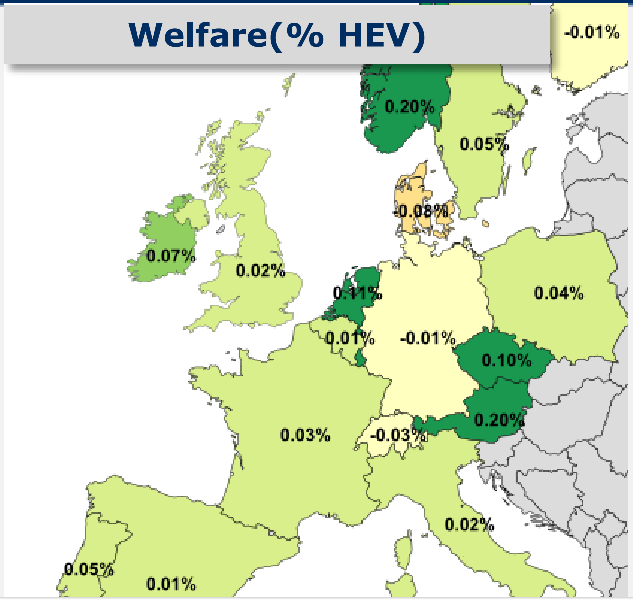
Macroeconomic Effects:

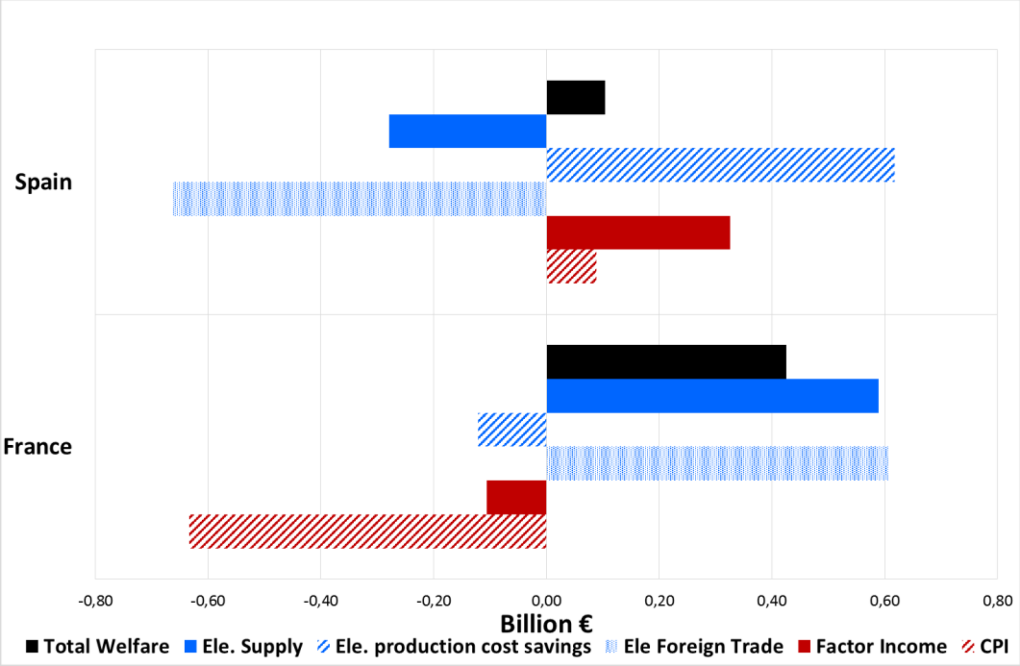
(1) Change in factor income

(2) Change in consumer price index (CPI)

Regional Impacts – TYNDP/RE 2020 Scenario

- Vast majority of countries gain from TYNDP
- “Categories” of countries:
  - Exporting countries (FRA, DEU, POL, CZE, AUT, NOR)
  - Importing countries (ESP, ITA, NLD, IRE)
  - “Wheeling” countries (DNK, CHE)
- Countries which experience welfare loss: DNK, CHE, DEU





Outline

Conclusions

1. *What is the effect of electricity grid expansion (Ten Year Network Development Plan, TYNDP), on aggregate and regional welfare in Europe?*
    a. Grid expansion of the TYNDP breaks even within 4-10 years
    b. “Electricity exporters” (vice versa for “electricity importers”): increased gains from electricity trade, adverse impacts from changes in factor income
    c. “Wheeling countries”: losses due to established bypasses

2. What is the interaction between grid and renewable energy expansion?
    a. Welfare gains of grid expansion are increasing in the level of renewable energy production

Conclusions (cont.)

How can relevant determinants of cross-country electricity trade be adequately represented within a macro-economic framework

➔ Hard-linking of macro-economic and sectoral electricity model

➔ Welfare changes from electric-sector and economy-wide adjustments tend to move in opposite directions

➔ Electricity-sector only perspective significantly over-estimates aggregate efficiency gains from grid expansion

Thank you for your attention.

Questions?

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