Macroeconomics of Electricity Generation

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Electricity generation

Introduction

Power (moving electrons) is a not storable form of energy that can be transported and transformed in many other forms of energy (motion, chemical, light, heat, etc.). Power generation uses many primary energies, including chemical energy from burning fossil fuels

Generation and load (final demand) has to be balanced in real time, with load having a very low real-time price-elasticity.

Top-down, high-voltage, large grid (interconnected) used to be the most efficient way to generate power and distribute it to the final user. The reduction of generation from fossil fuel and the introduction of intermittent (variable) renewable generation is the largest challenge in the coming decade and has macroeconomic consequences.

Definitions

Intermittent power generation experiences *undesired* variations

Dispatchable power generation allows *desired* variations (to balance demand and supply in real time)

Coal power plant in Poland

Fossil-fuel power plants

Coal-fired

Chemical to heat to motion to electricity (Carnot cycle). Concentrated, low efficiency (around 40%), high responsiveness

Open-Cycle and Combine-Cycle Gas Turbines

Chemical to heat to motion to electricity. Concentrated, very high responsiveness. Combined-cycle is more expensive to build but more efficient (around 60%)

Non fossil-fuel power plants

Hydroelectric and nuclear

Hydroelectric: Motion to electricity. High fixed-cost and (close to) zero marginal cost. Can be also a pumped-storage hydropower (PSH). High efficiency and very high responsiveness

Nuclear: weak nuclear force to heat to motion to electricity. Very concentrated, low efficiency. High fixed-cost and (close to) zero marginal cost.

VRE

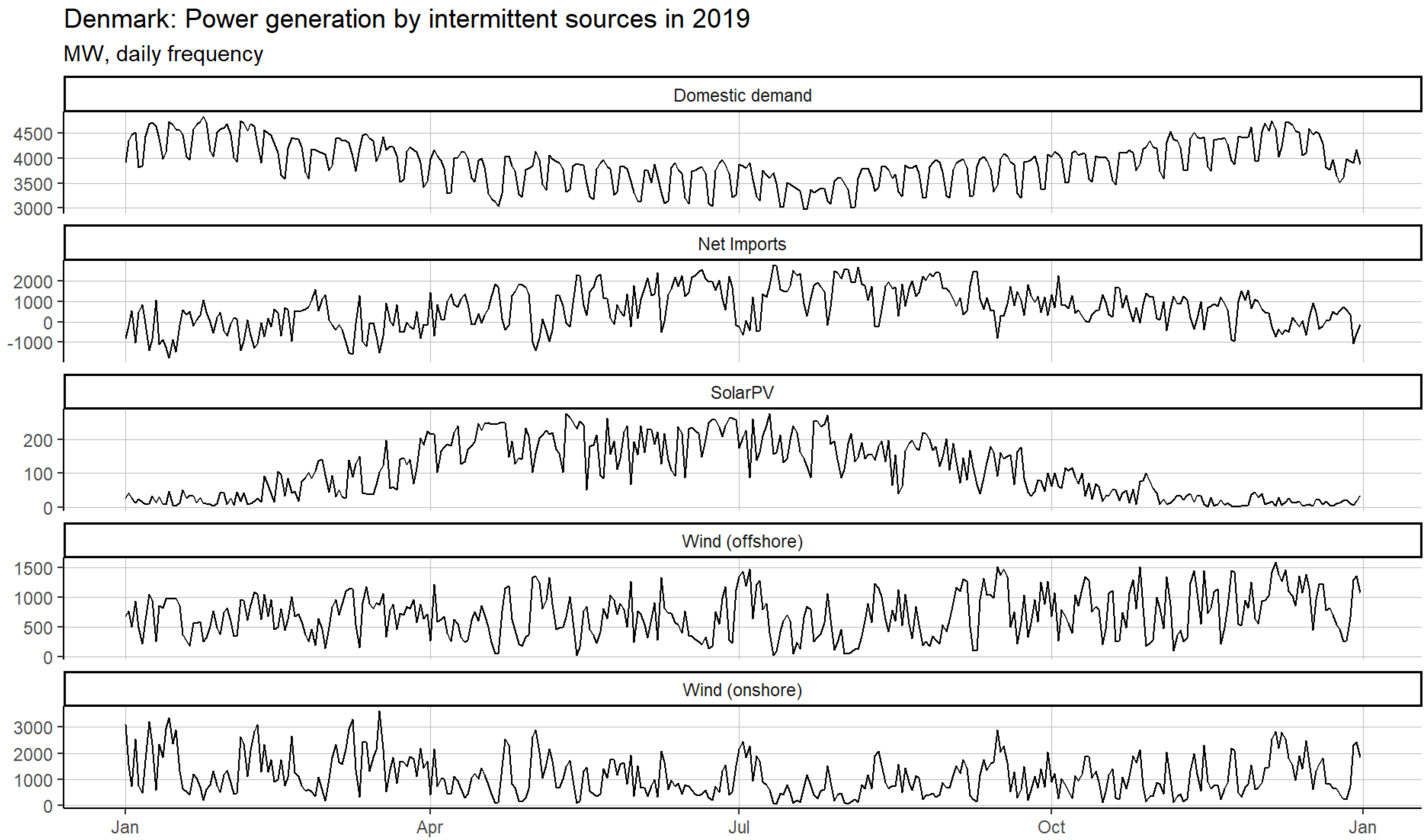
Solar photovoltaic: Light to electricity. Dispersed and intermittent (daily and seasonal) energy, low efficiency (not a depletable resource). high fixed cost, low marginal cost

Wind: Motion to electricity. Dispersed and intermittent (three-days and seasonal) energy, medium efficiency (not a depletable resource). high fixed cost, low marginal cost

Others

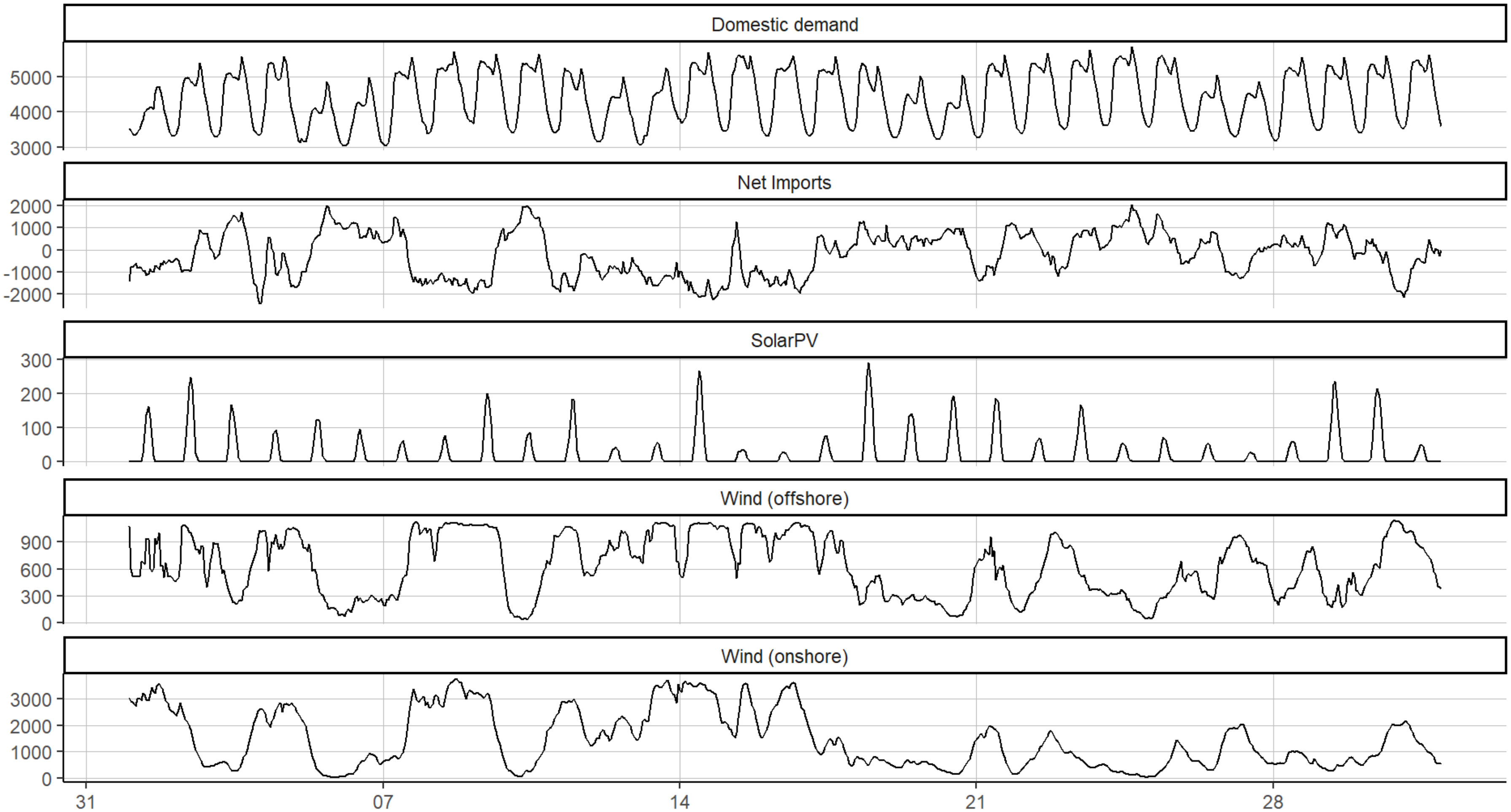
- Geothermal, tidal, solar thermal

Variable Renewable Electricity


Denmark: Power generation by intermittent sources in 2019
MW, daily frequency
Domestic demand
4500
4000
3500
3000
Net Imports
2000
1000
0
-1000
SolarPV
200
100
0
Wind (offshore)
1500
1000
500
0
Wind (onshore)
3000
2000
1000
0
Jan
Apr
Jul
Oct
Jan

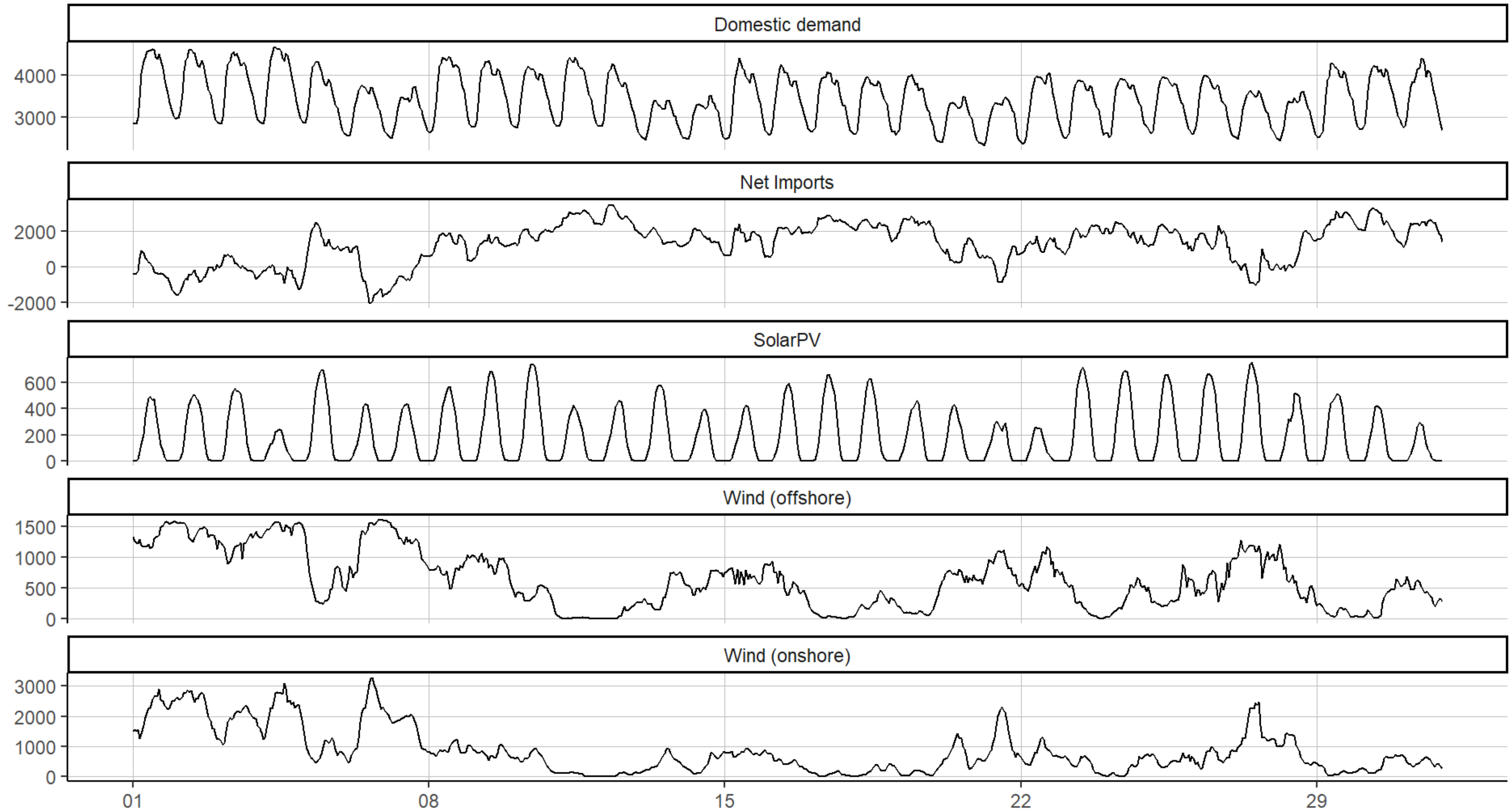
Denmark: Power generation by intermittent sources in January 2019

MW, hourly frequency



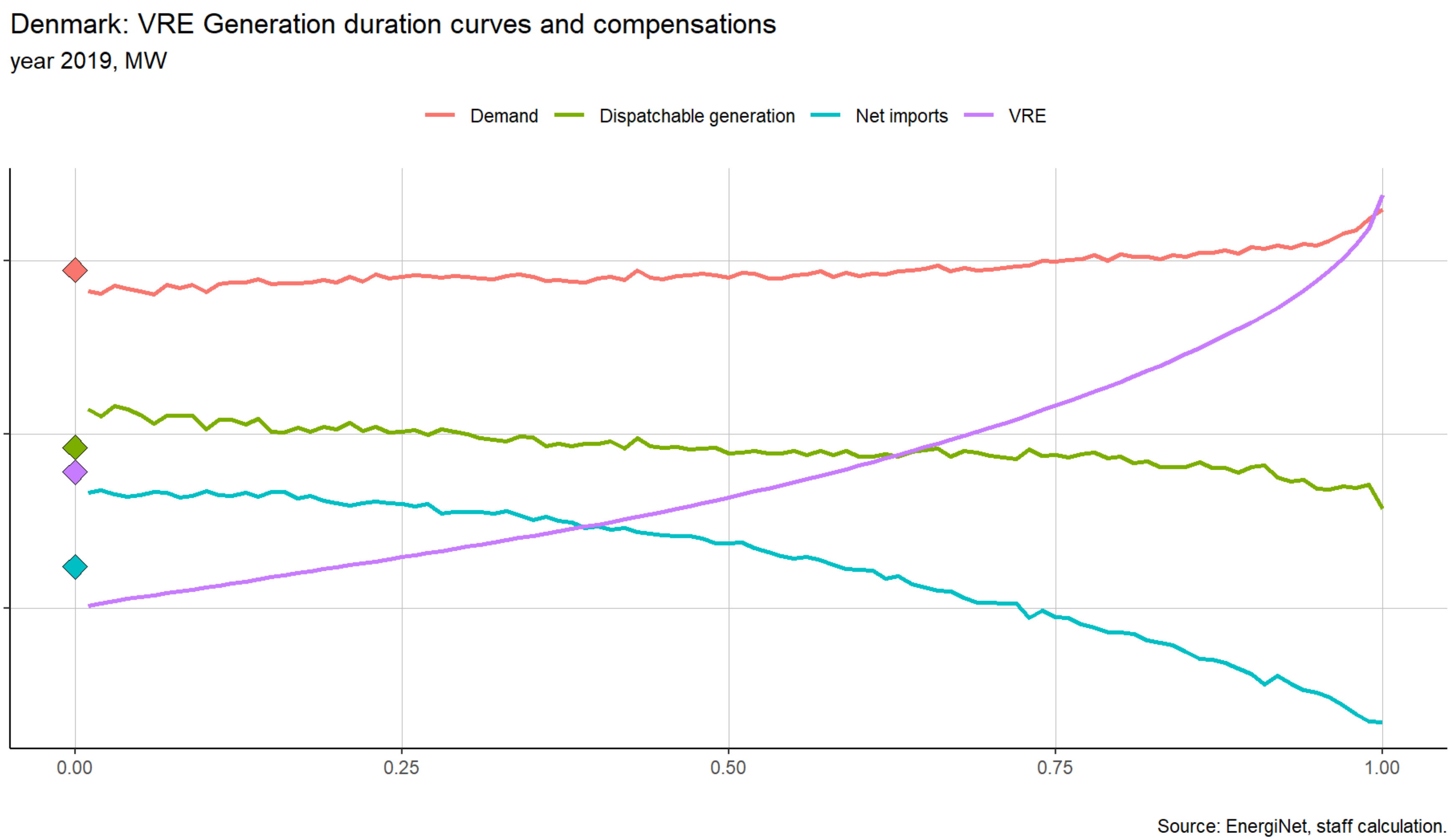
Denmark: Power generation by intermittent sources in July 2019

MW, hourly frequency



Generation duration curves

distribution of real time power generation



Copying with intermittency

To generate the *desired* level of power in real time, an intermittent generation requires

Backup

- dispatchable
- idle capacities
- “rest of the grid”

Curtailment

- High regime is under-used

Storage

- PSH
- Batteries

Cost and value of electricity

Levelized cost of electricity (LCOE)

LCOE: average net present cost of electricity generation for a given power plant over its lifetime

Fixed vs variable costs

- Low fixed cost / high variable cost: natural gas, coal
- High fixed cost / low variable cost: nuclear and hydro, VRE

$\Rightarrow$ Coal and natural gas LCOE depends on fuel costs.

Time-to-build

- Nuclear power plant: 8 years to build (70% of the cost), 50 years to generate (20% of the cost), and 10 years to decommission (10% of the cost)

$\Rightarrow$ Nuclear and hydro LCOE depends on the discount factor

Series production

- Large scale nuclear, one Giga Watt (GW), and hydro power plants do not benefit from cost reduction with number of installed units. VRE much more

$\Rightarrow$ VRE LCOE depends on the size of the market

Value of electricity

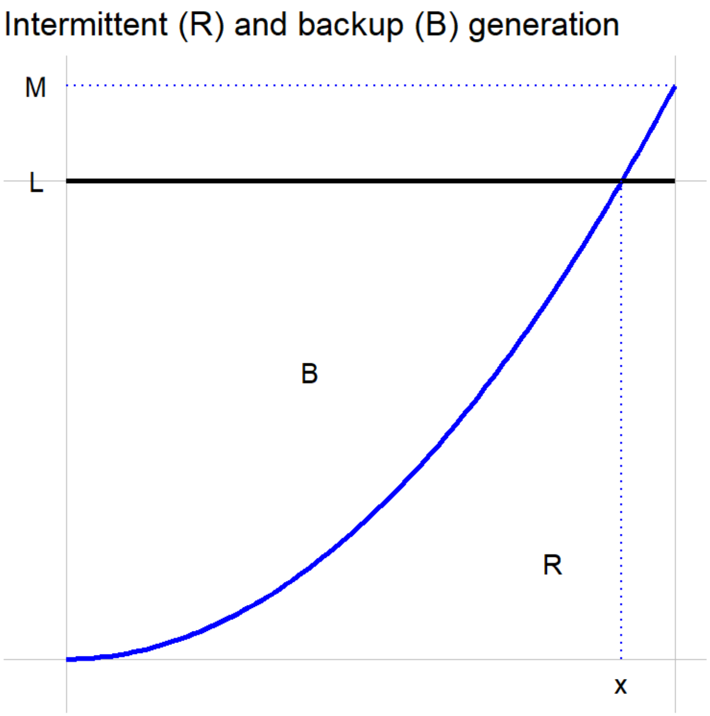
Decentralized allocation

- Electricity market balanced in real time $\Rightarrow$ the wholesale price (real-time value of the marginal electricity generated) is volatile and (inversely) correlated with intermittent generation.
- The average value of VRE is lower than the average value of electricity from natural gas (largest marginal cost).
- Storage capacities (in the grid), higher price-elasticity of final demand (storage capacities out of the grid,), and interconnection smooths the wholesale price (the value of VRE increases and the value of natural gas decreases). - Large pecuniary externalities.

Centralized allocation The centralized (first-best) allocation is (in general) different but the same ideas remain.

- Comparing generation costs of an intermittent and a dispatchable source is not economically accurate.
- A more accurate method adds intermittent generation costs + backup and storage costs to upgrade from intermittent to constant.

Intermittent plus backup



- Constant desired load L
- Renewable capacities $M > L$

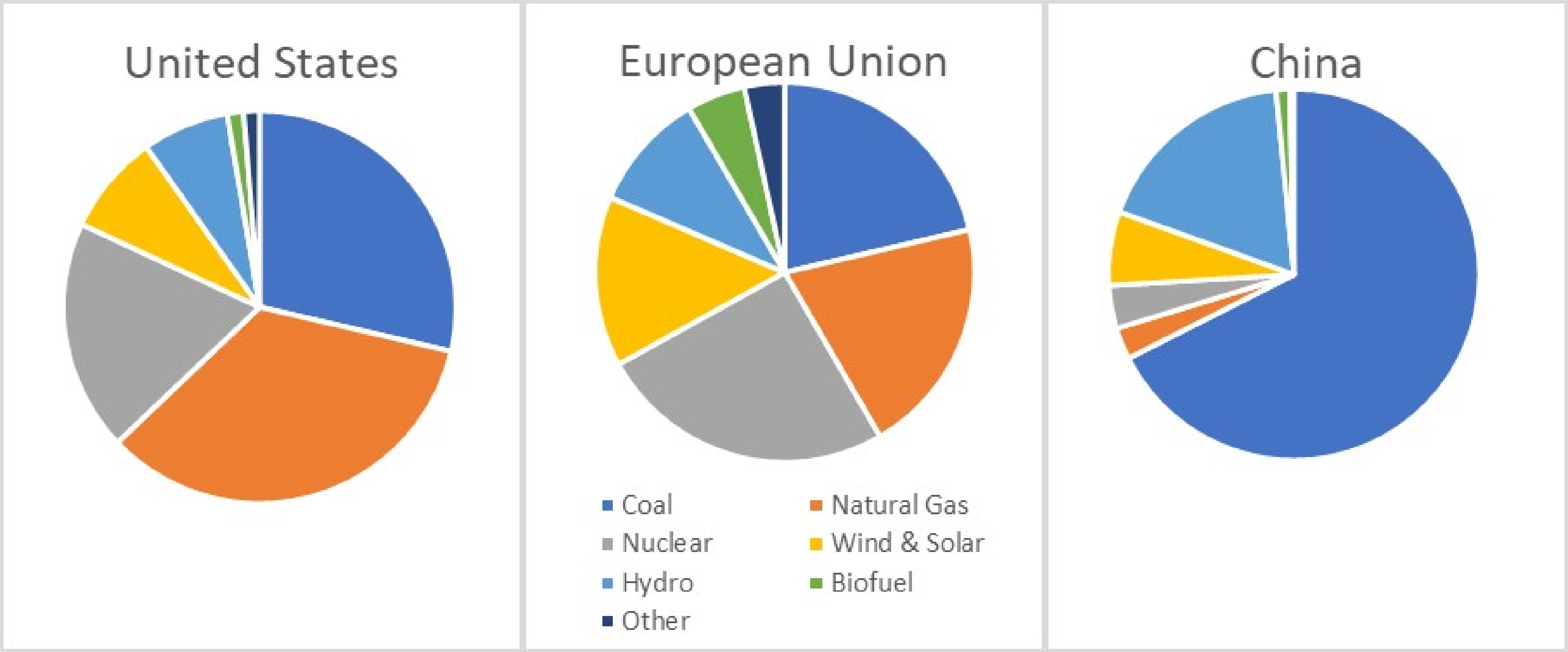
$$P = Mx^{\gamma}$$

- Backup capacities $\bar{B} = L$
- Backup generation B

$$C = P_M M + P_{\bar{B}} \bar{B} + P_B B$$

Macroeconomics

Electricity generation by source (2018)



Electricity generation represents around 2% of GDP, but it has a larger macroeconomic impact

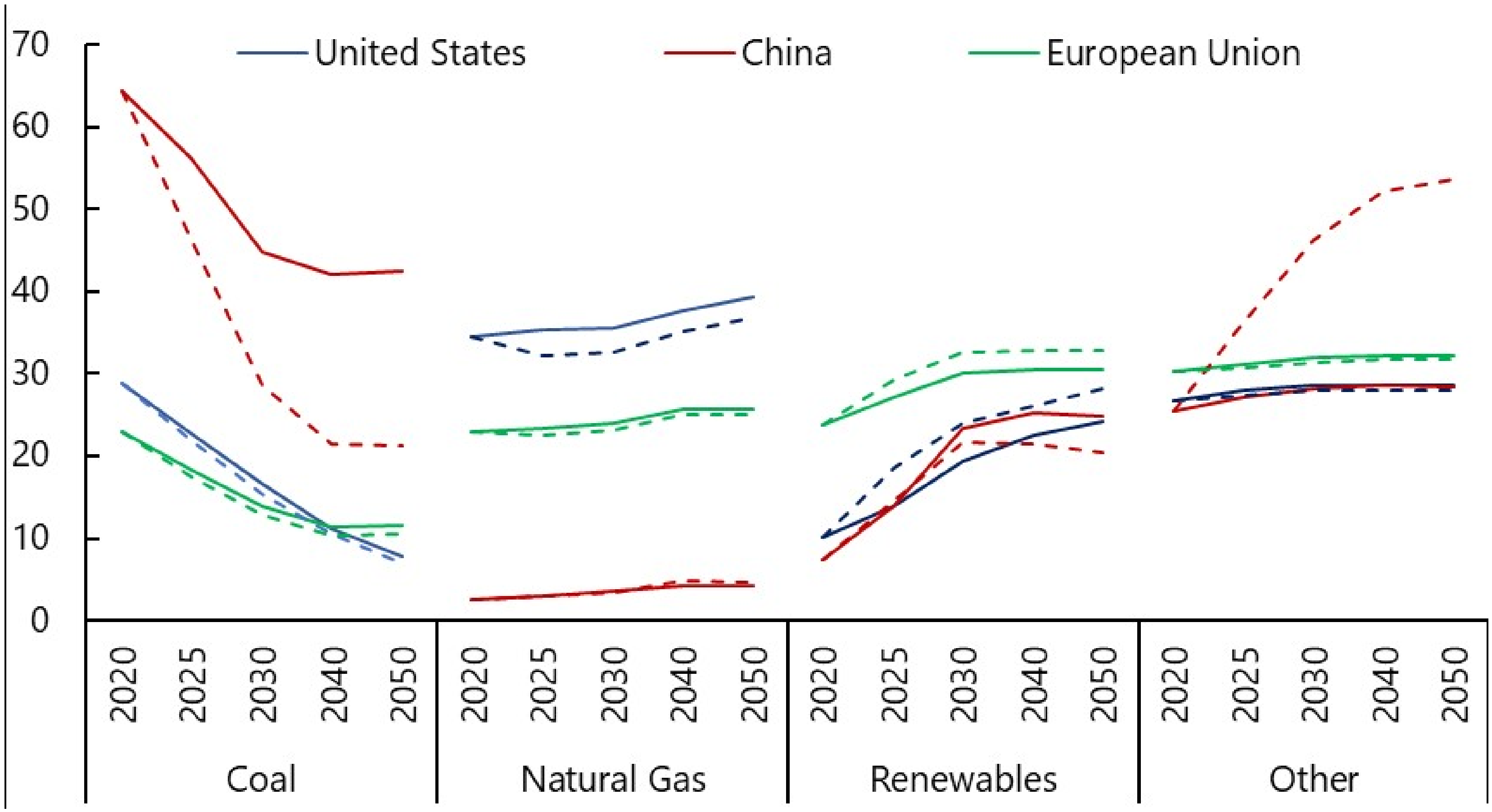
- universal input of production
- low price-elasticity of demand (GDP = power)

Simulations

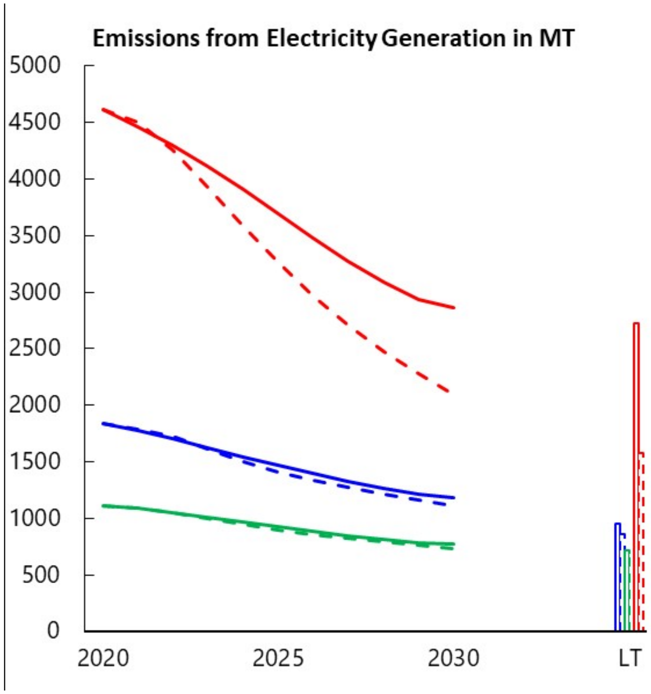
Experiment

- 50 USD carbon price phased in over 10 years
- policy package:
  - frontloaded renewables investment subsidies;
  - accommodative monetary policy;
  - doubling of nuclear and hydro capacities over ten years (China).

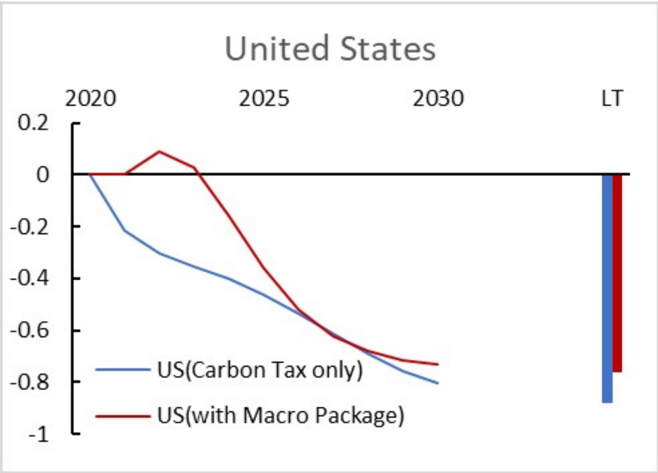
Electricity generation by source

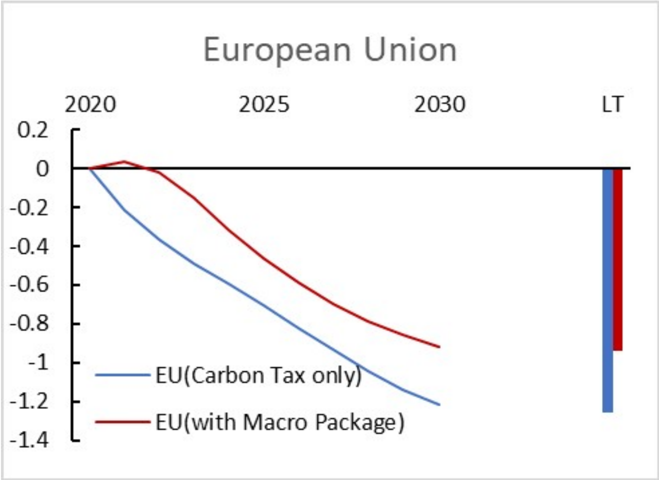


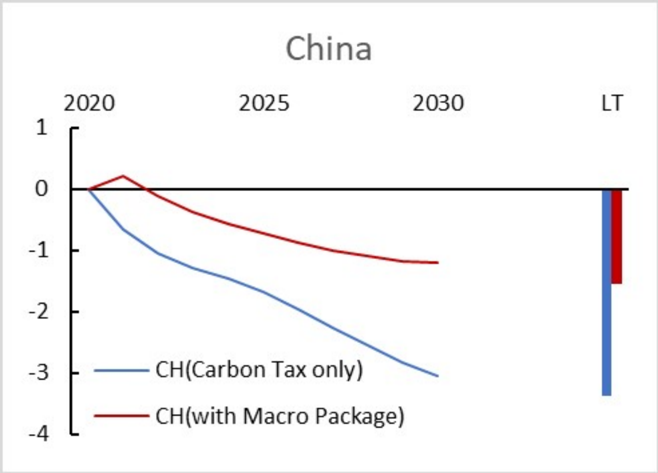
GHG emissions



GDP


United States
2020
2025
2030
LT
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
US(Carbon Tax only)
US(with Macro Package)


European Union
2020
2025
2030
LT
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
EU(Carbon Tax only)
EU(with Macro Package)


China
2020
2025
2030
LT
1
0
-1
-2
-3
-4
CH(Carbon Tax only)
CH(with Macro Package)

Discussion

Where natural gas is abundant (USA), the penetration of intermittent generation has large climate benefit at a low economic cost

- intermittent capacities save an expensive fuel (natural gas) in a the mix
- The mix saves a carbon intense (coal) generation

Where natural gas is rare (China), intermittent generation requires large storage capacities to have an economic and climate benefit

- without storage, the main impact of renewable extension is to reduce coal as main and expand coal as backup with a high economic cost and a low climate benefit
- nuclear and hydro generation has more economic and climate benefits