Quantifying Integration Costs of Variable Renewable Energy Technologies in European Energy Systems

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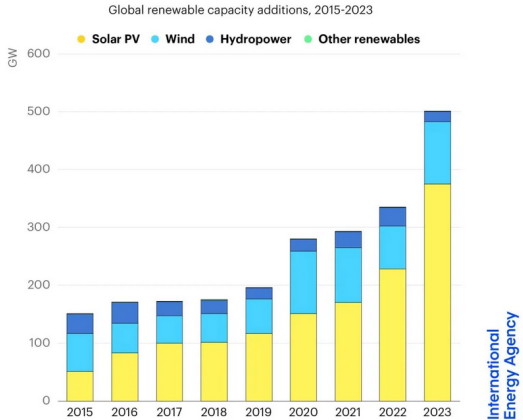
Introduction

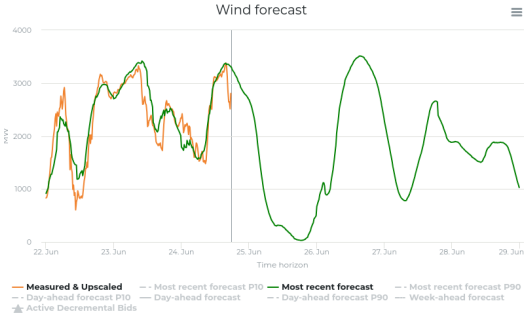
Introduction

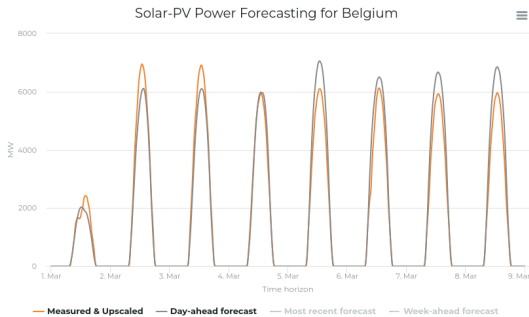
The world added a historic 510 GW of renewable capacity in 2023, equivalent to the entire power capacity of Germany, France & Spain combined



Introduction

Characteristics of VRE technologies! Uncertainty and Variability



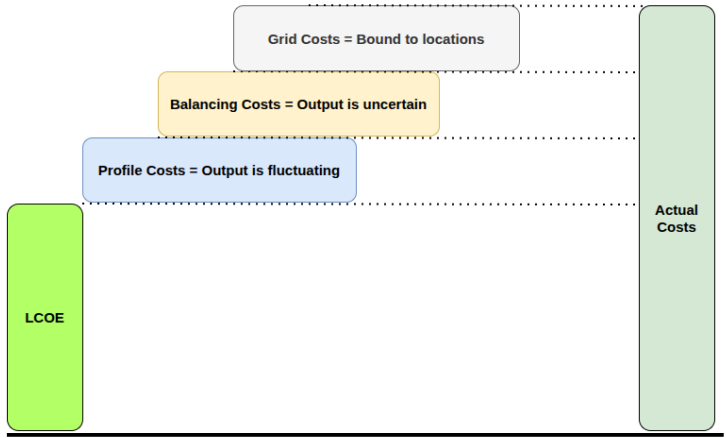


A perfect forecast eliminates uncertainty, but variability remains

Courtesy: Elia Dashboard

Introduction

Integration costs: the additional system cost when integrating VRE

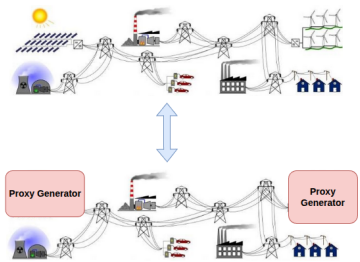


Addapted from Ueckerdt et al. 2013

Introduction

Methodologies used to compute integration costs (literature review)

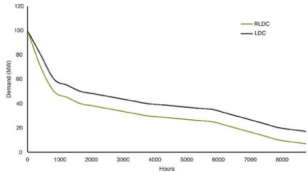
Cost production model method



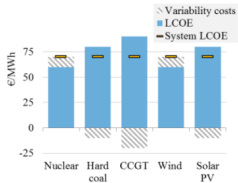
Different Metrics

VALCOE | ACOE | LACE

Load duration curves method



System LCOE method



Methodology

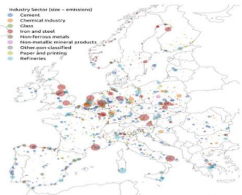
Objective

Compute the integration costs in a simple and straightforward way!

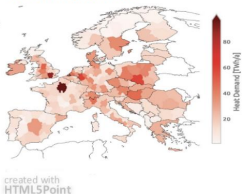
Utilize an energy system model

Why PyPSA-Eur?

Industrial sector model

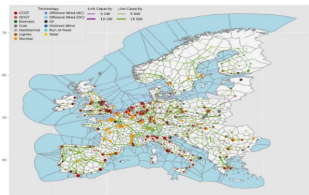


Heat demands

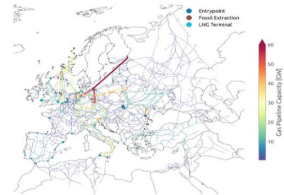


Workflows and scripts to extract all demands, generation, potentials, ...

Existing grid and power plants



Detailed gas grid model



Hourly time series

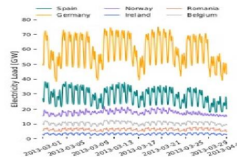


Image credentials: PyPSA-Eur

Methodology

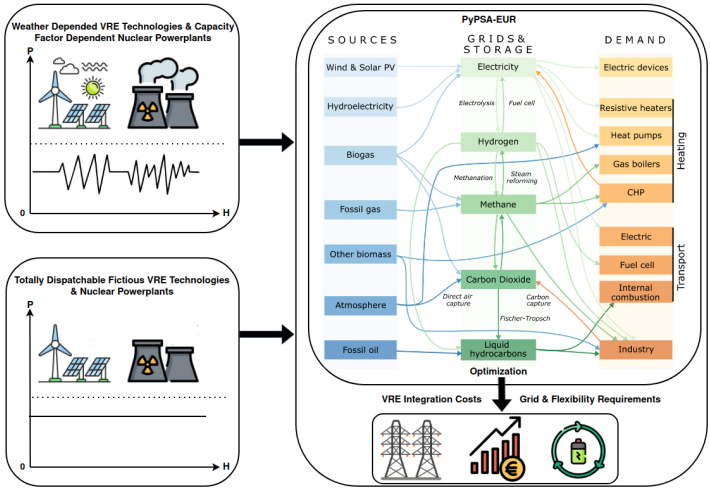
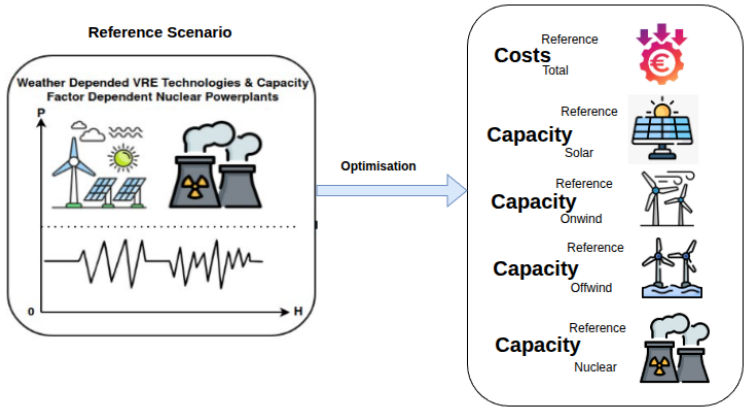


Image credentials: PyPSA-Eur

Methodology

Reference scenario computes the total annualised system costs and optimised capacities of renewable technologies



Methodology
Example: Solar Scenario

Capacity Constraints

$$\text{Capacity}_{\text{Solar}}^{\text{Solar Scenario}} \leq \text{Capacity}_{\text{Solar}}^{\text{Reference}}$$

$$\text{Capacity}_{\text{Onwind}}^{\text{Solar Scenario}} \leq \text{Capacity}_{\text{Onwind}}^{\text{Reference}}$$

$$\text{Capacity}_{\text{Offwind}}^{\text{Solar Scenario}} \leq \text{Capacity}_{\text{Offwind}}^{\text{Reference}}$$

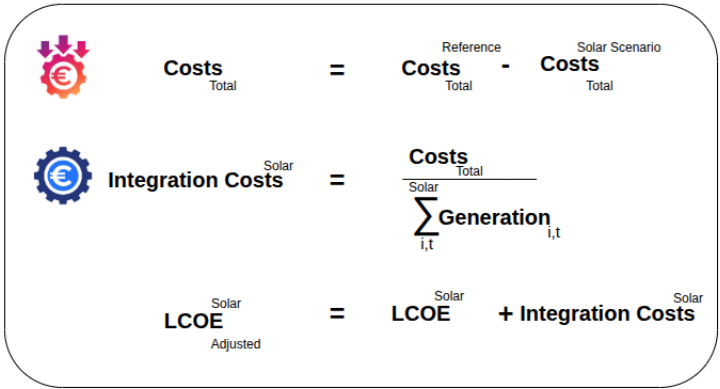
Generation Constraints

$$\sum_{i,t} \text{Generation}_{i,t}^{\text{Solar Scenario}} \leq \sum_{i,t} \text{Generation}_{i,t}^{\text{Reference}}$$

Modified Capacity Factor

$$0 \leq \text{Capacity Factor}_{\text{Solar}} \leq 1$$

Methodology
Example: Solar Scenario



Straight forward computation of integration costs

Scenarios

Scenarios

5 Scenarios: Solar, Onshore Wind, Offshore Wind, VRE, Nuclear

Considered Nodes: BE, FR, NL, GB, DE

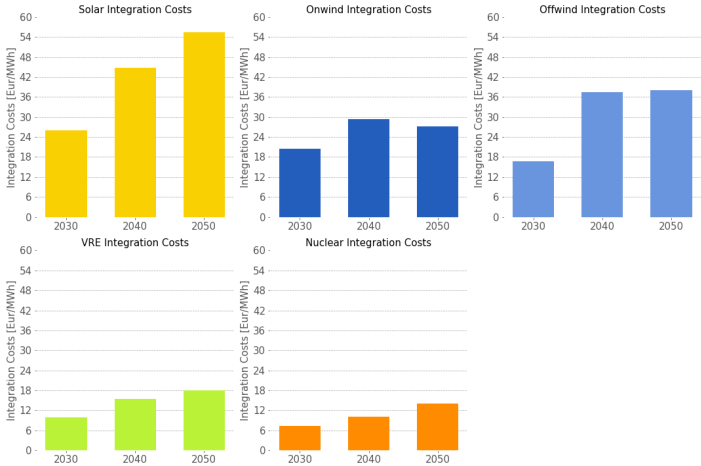
Optimisation: Greenfield and brownfield

Configuration:

- Carbon budget: 2030 (–55%), 2040 (–85%), 2050 (net zero)
- Current demand projections + expected efficiency improvements
- Transmission lines espansion, 50% in each planning horizon
- Increased EV shares upto 85% by 2050
- CCS is allowed

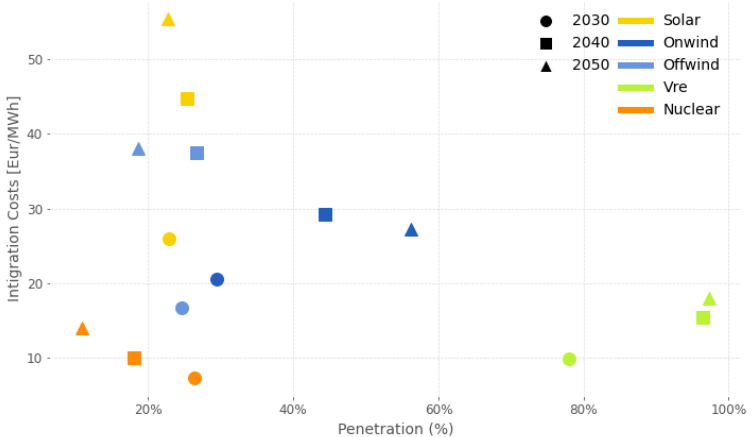
Results

Results
Integration costs in all scenarios

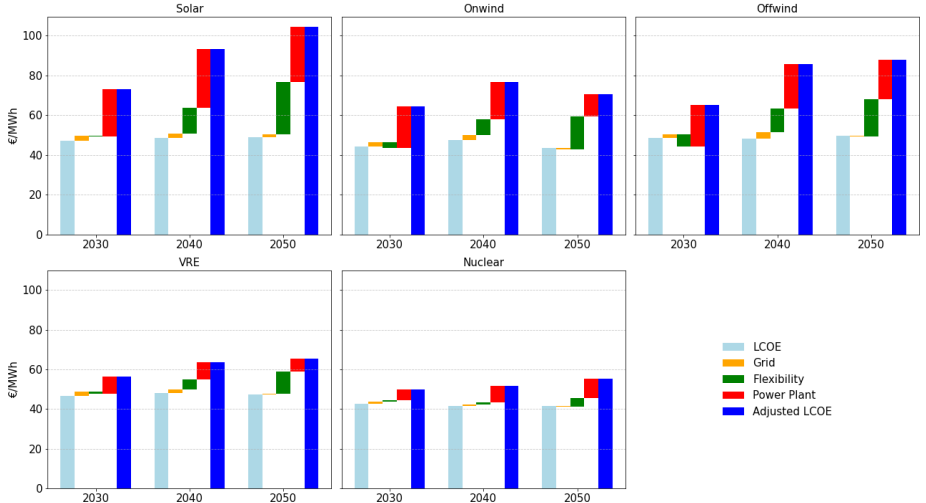


Results

Integration costs with penetration level in power system



Results
Distribution of integration costs



Conclusions

Conclusion and Future Work

Conclusion:

- Integration costs computations can be made in a simple way using existing modeling tools.
- Individually, these costs can be very high for some VRE technologies like solar.
- Policy measures have a big impact on VRE integration; when combined, integration costs remain marginal even above 80% penetration.

Future Work:

- Extending the study on regional level.
- Comparison of results with other studies.
- Sensitivity analysis.

Thank You!