Long-term issues with the energy-only market design in the context of electricity decarbonisation

Insights from a system dynamics simulation model

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Outline

Motivations

Most of the decarbonisation is ahead of us and many questions are still pending regarding techno-economic and organisational considerations.

Traditional modelling approach in prospective analysis resorts to Generation Expansion Planning models (GEP).

Investors' behaviour and available information are crucial elements for investment and decommissioning trajectories. GEP are not suited for a comprehensive discussion on theses aspects:

- Their outcome correspond to perfect competition with fully rational and informed agents
- No explicit representation of the decision making process.

Questions

Simulation models allows for explicit modelling of investors' behaviour evolving in a given market structure. The System Dynamic framework is well suited for our scope.

As part of a broader discussion on market design and decarbonisation, this presentation focuses on the Energy-Only Market (EOM).

1. which assumptions about investor behaviour and available information are needed to ensure that an EOM induces the target mix trajectory, i.e. that which achieves decarbonisation objectives at least cost?
2. how robust is an EOM (as measured by deviations between realized vs. optimal mix trajectories) when different assumptions are considered?

Takeways

First findings based on an illustrative case inspired by the Californian power system:

1. Energy-only market (completed with a carbon price signal) is able to track and reproduce the optimal mix trajectory **but required assumptions are demanding and do not fit with reality**, i.e. perfect rationality, perfect information (about future investment and decommissioning decisions, demand, fuel & carbon prices, etc.), perfect coordination between decommissioning and investment decisions.
2. **When relaxing some of these theoretical assumptions (to switch to more realistic ones) mix trajectory of the energy-only market can considerably deviate from the optimal trajectory**.

While an EOM looks appealing in theory, its desirable properties suffer from a lack of robustness with regard to practical investor behaviors.
In turn, it is necessary to define a more adapted market design, e.g. in the form of hybrid markets that rely on long-term arrangements alongside short-term markets as we know them today.

Articulation between optimization and simulation

Two models: CO_2-constrained GEP and System Dynamic simulation.

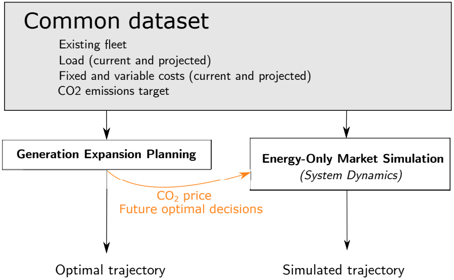


Figure: Modelling framework

↑ The SD model can be fed by some information from the optimal trajectory

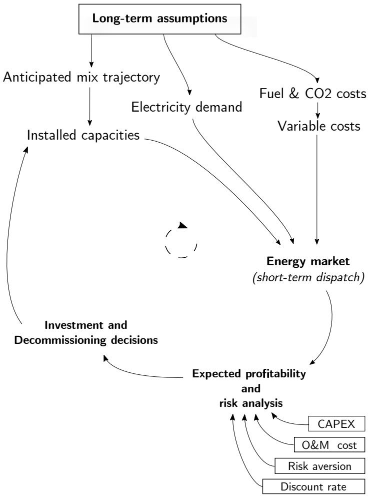
Overview of SD model

Model similar to Bunn Dyner 1996, de Vries 2008, Petitet 2017 etc.

Key elements:

- Endogenenous investment and decommissioning in thermal, variable renewable and storage technologies
- Particular emphasis on anticipated capacities (Tao et al. 2019)

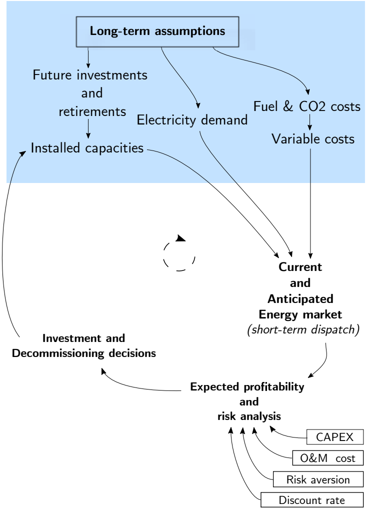
Investment and decommissioning decisions are representend year by year, project by project.



Step 1

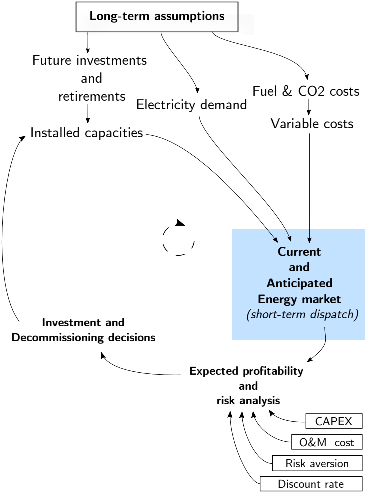
In the current year, investors and generation asset owners make assumptions about the future:

- projected load
- projected variable and fixed costs
- future investment and decommissioning decisions



Step 2

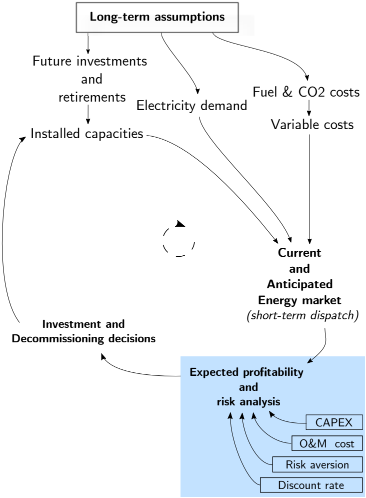
Based on this anticipation, a dispatch model is used to derive future market conditions: hourly generation and captured price for each technology (existing or candidate).



Step 3

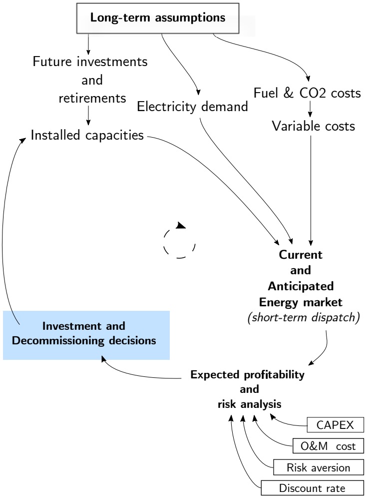
Net Present Values are calculated for both candidate technologies and the existing fleet.

Regarding fixed costs, candidate technologies have to recoup fixed O&M + CAPEX. The existing fleet only has to recoup fixed O&M (CAPEX are already engaged and can no longer be saved).



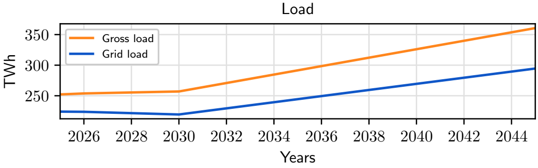
Step 4

Based on the economic assessment of different available options, investment or decommissioning decisions are taken. The installed capacities are updated in the mix (current and anticipated).

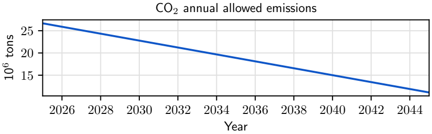


Stylized California case study

All data adapted by authors from CPUC's RESOLVE, NINJA Renewable and historical data.



Stagnating demand until 2030, then strong increase pushed by electrification up to 2045.



In a context of strong reduction of CO_2 emissions (- 60% throughout the study horizon).

California case study : endogenous generation

Four technologies endogenously represented (investment or decommissioning decisions)

Technology	Available decision	CAPEX	Fixed O&M	Fuel Cost	Carbon intensity
-	-	[USD/kW-Yr]	[USD/kW-Yr]	[USD/MWh]	[tCO_2/MWh]
CCGT	Decommissioning	126	11	Average: 31 (see app.)	0.37
Peaker	Decommissioning	46	14	Average: 51 (see app.)	0.61
PV	Investment & decommissioning	70	9	0	0
Storage	Investment & decommissioning	82	10	0	0

The storage technology is assumed to have a 4 hours duration and a 85% round-trip efficiency.

Common WACC: 8 %

Value of Loss Load: 20 USD/kWh

Results from the CO_2-constrained GEP model

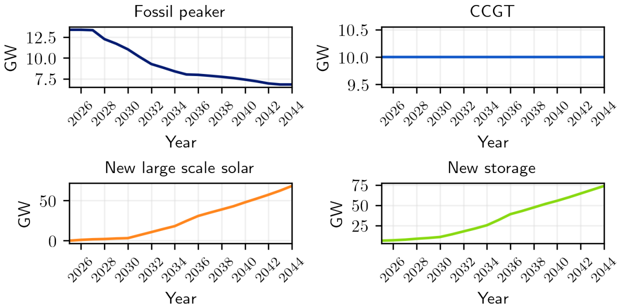


Figure: Optimal development trajectories

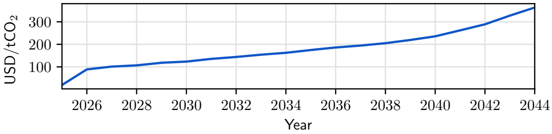


Figure: CO_2 shadow price

Assumptions

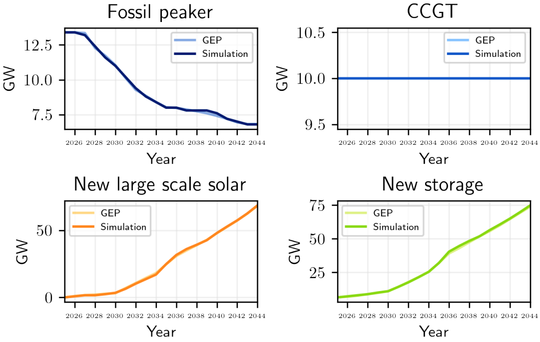
Perfect information in the Energy-Only Market SD model

In order to trigger the optimal investment and decommissioning decisions, perfect information over the period 2025-2045 are required about:

- Electricity demand
- Fossil fuel prices
- CO_2 price
- Current and future investment and decommission decisions

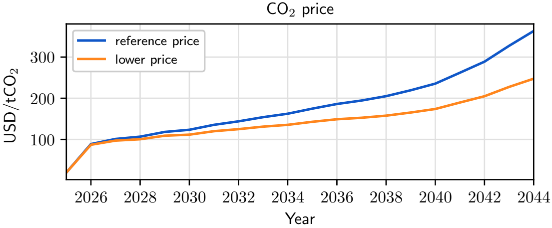
Results: SD model with perfect information

Under these assumptions, the SD model produces a trajectory that is close to the optimal trajectory.



⚠ Lumpiness of units → slight differences between the optimal trajectory and the market model.

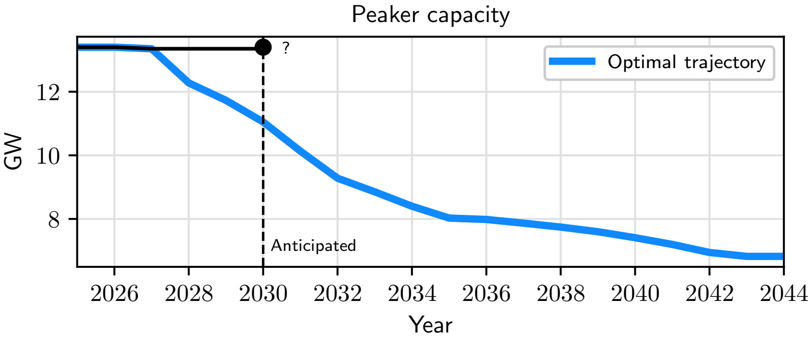
Assumption: conservatism in the CO_2 price projection (all other things being equal)



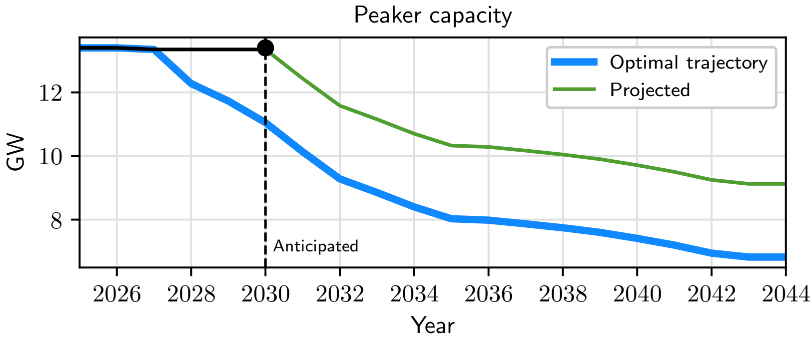
Two elements need to be discussed regarding our set of modelling assumptions:

1. How anticipations are updated if a deviation occurs during a certain year ?
2. Considering a sequential implementation of investment and decommissioning decisions, what should be the anticipations in each module ?

Adaptation of projected capacities

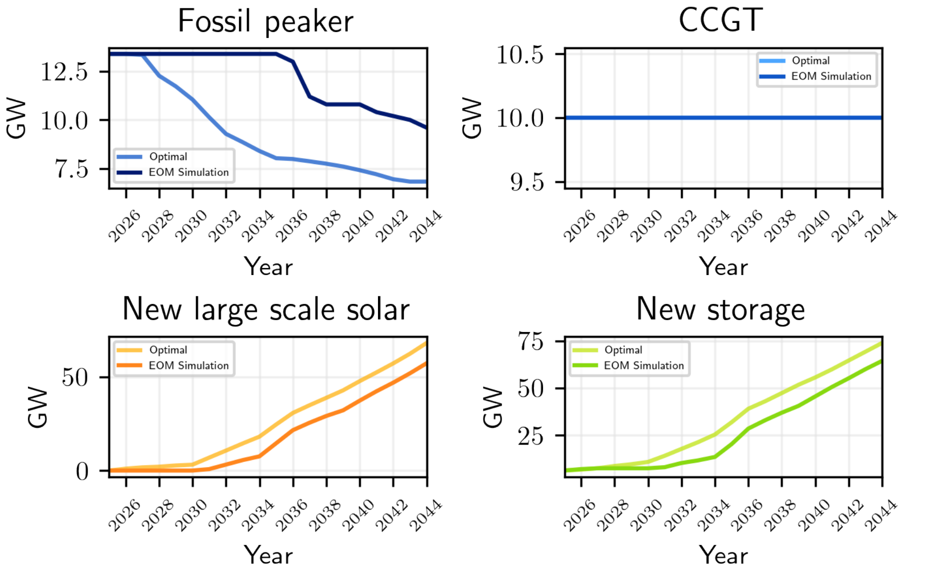


Adaptation of projected capacities



If a deviation occurs, the anticipated trajectory follows the initial pace (more realistic)

Results with a lower CO_2 price



Modelling contributions

System Dynamics methodology completes the economic toolbox to analyze electricity market designs and decarbonization. It is complementary to

- generation expansion models (GEP) because it is possible to explicitly represent market design, information available and investors behavior
- equilibrium market models, given that it allows to analyze "out of equilibrium" situations which are the norm in power systems.

In this paper, we develop a System Dynamics model with endogenous investment and decommissioning decisions to study the properties of an energy-only market. We compare SD market results using different information assumptions with GEP optimal decarbonization trajectory.

Policy insights

We show that generation mix can considerably deviate from the optimal trajectory when relaxing some theoretical assumptions of the pure EOM design.

Thus, it is necessary to define a more robust market design to ensure power system decarbonization at least cost, e.g. in the form of hybrid markets that rely on long-term arrangements alongside short-term markets as we know them today.

Further work

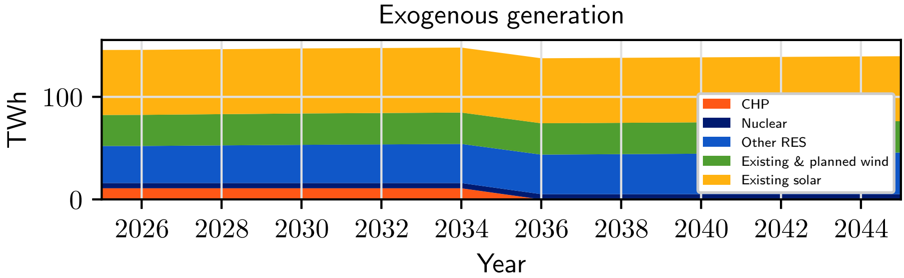
Models and methods developed here allow to extend our work in several ways:

- **Multiple scenarios & risk preference:** our case study only considers one (future) scenario but the SD model has been built to manage multiple (future) scenarios, allowing analyses of different risk preferences of investors
- **Alternative market designs:** our SD model also includes alternative market designs based on tenders and long-term contracts
- **Market design robustness to unexpected trend changes:** in our case study key parameters (technology costs, demand, etc.) evolve gradually during the simulation period; there is no disruptive trend changes. Our SD model can be also used to analyze the robustness of different market design to disruptive changes (e.g., assessing sunk costs and the general impact of irreversible investment and decommissioning decisions).

Acronyms

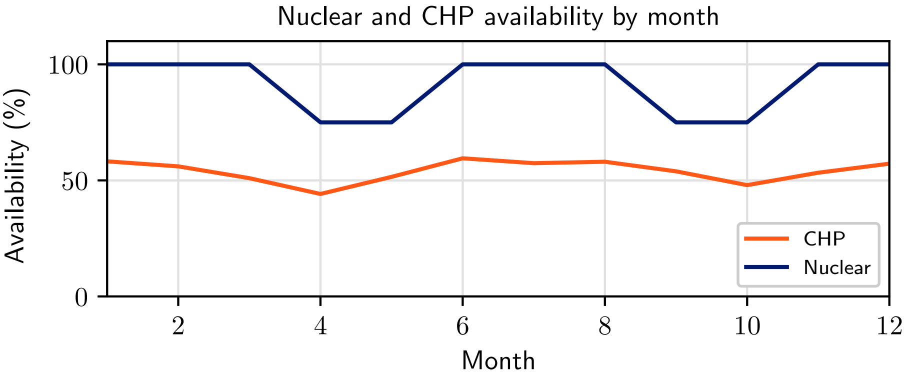
Acronym	Meaning
CCGT	Combined Cycle Gas Turbine
CHP	Combined Heat & Power
GEP	Generation Expansion Planning
RES	Renewable Energy Sources
WACC	Weighted Average Cost of Capital

Exogenous generation



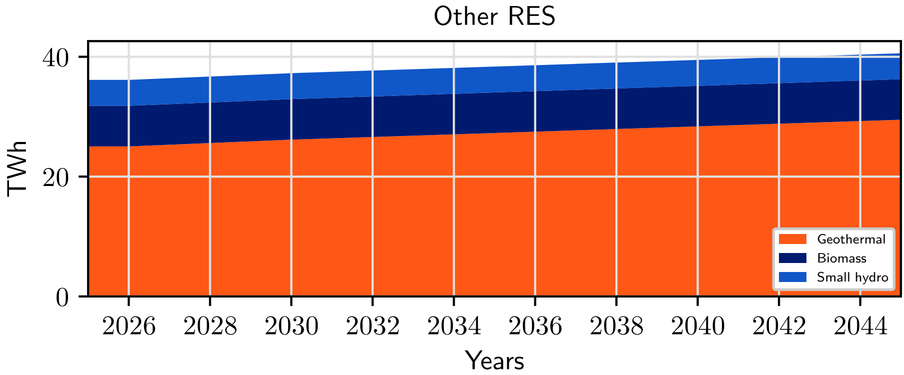
A certain number of generating technologies is exogenous in terms of investment and decommissioning decisions. Their generation is still modelled at an hourly level (see appendices for assumptions).

Nuclear and CHP



Full power generation is assumed when available (RESOLVE)

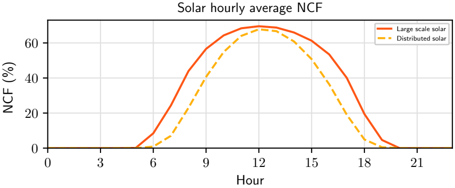
Other RES



Steady generation is assumed within each year (RESOLVE)

Wind and solar capacity factors

27% average CF for large scale solar and 21% for small scale. No tracking for small scale (more concentrated generation in the middle of the day)



26% average capacity factor