POLITECNICO DI TORINO
Dipartimento di Ingegneria Meccanica e Aerospaziale

Optimal strategies for renewable energy conversion systems integration

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Scholarship: Integrated Renewable Power Sources and Energy Storage Solutions - Energy Center Lab

State-of-the-art

Energy system models

Top-down

Economic approach

Macroeconomic relationships

Study of the **impact of market measures**

Bottom-up

Detailed **technological description**

Focus on the **energy sector** only

High amount of **exogeneous variables**

Descriptive models

Detailed description of the **system operation**

Each set of fixed parameters generates a scenario

Time simulations with relatively high computational cost

EnergyPlan, HOMER, IPSA 2, LEAP, RAPSim, RETScreen, WEM

Prescriptive models

Aimed at identifying the **optimal set of variables** for minimizing an objective function

Make use of **optimization techniques**

Technical, regulatory and environmental constraints as conditions

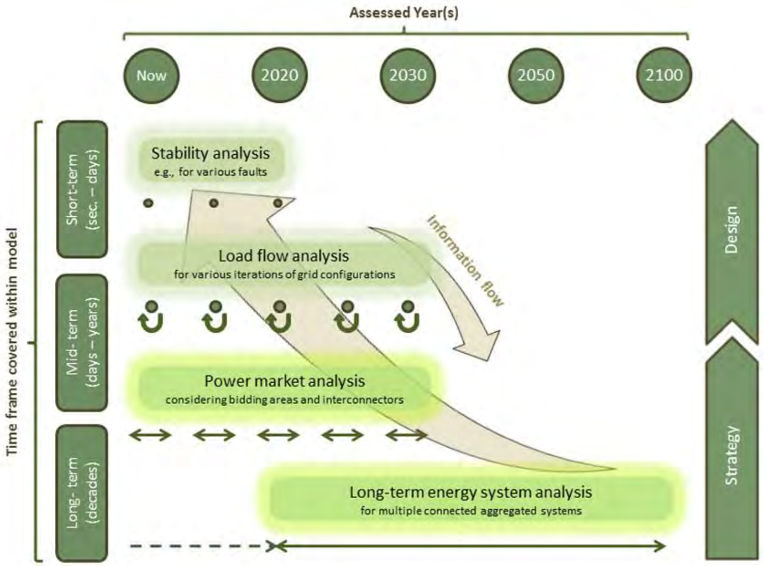
BALMOREL, COMPOSE, DER-CAM, EMMA, MARKAL, OSeMOSYS, PLEXOS, TIMES

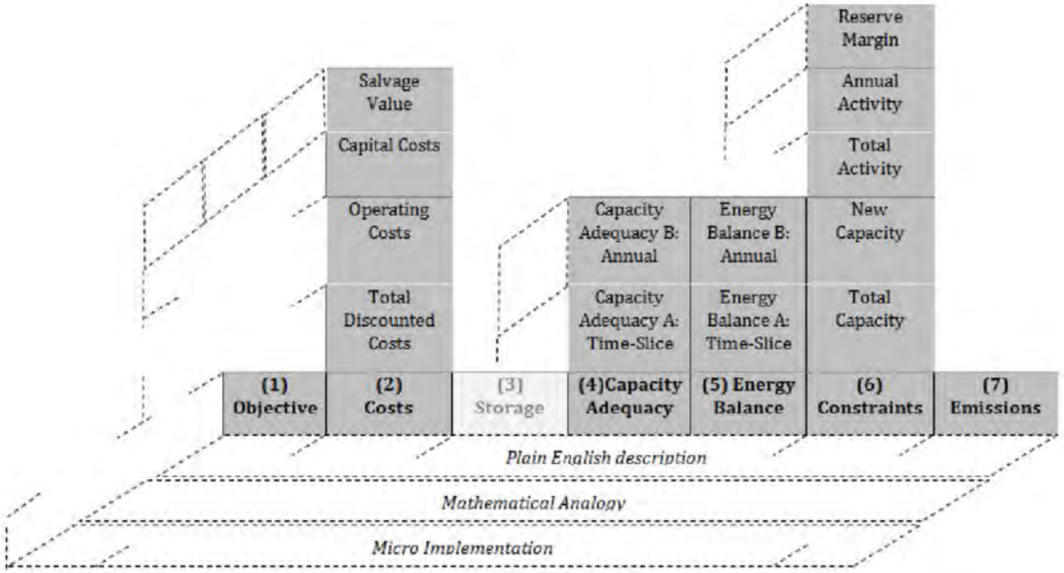
- Ringkjøb, Hans-Kristian, Peter M. Haugan, and Ida Marie Solbrekke. "A review of modelling tools for energy and electricity systems with large shares of variable renewables." Renewable and Sustainable Energy Reviews 96 (2018): 440-459.

OSeMOSYS and the model structure

- **OSeMOSYS** (Open Source energy Modelling SYStem) generates **deterministic**, **(mixed integer) linear optimisation** models for supporting **medium- to long-term energy strategies**
- Developed in GNU MathProg, then into GAMS and **Python-Pyomo**
- **Objective function:** total energy supply cost over the modelled period
- **Boundary conditions:** equations and inequalities for match of supply and demand, cost and performance of technologies, constraints on capacity addition and operational constraints, decarbonization targets, characteristics of storage systems

➢ **Addition of storage equations on Python-Pyomo and novel equations for ensuring grid stability by means of adjustable power production tecnologies**

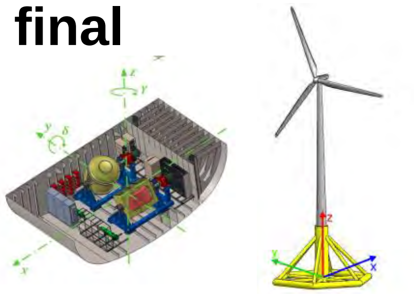




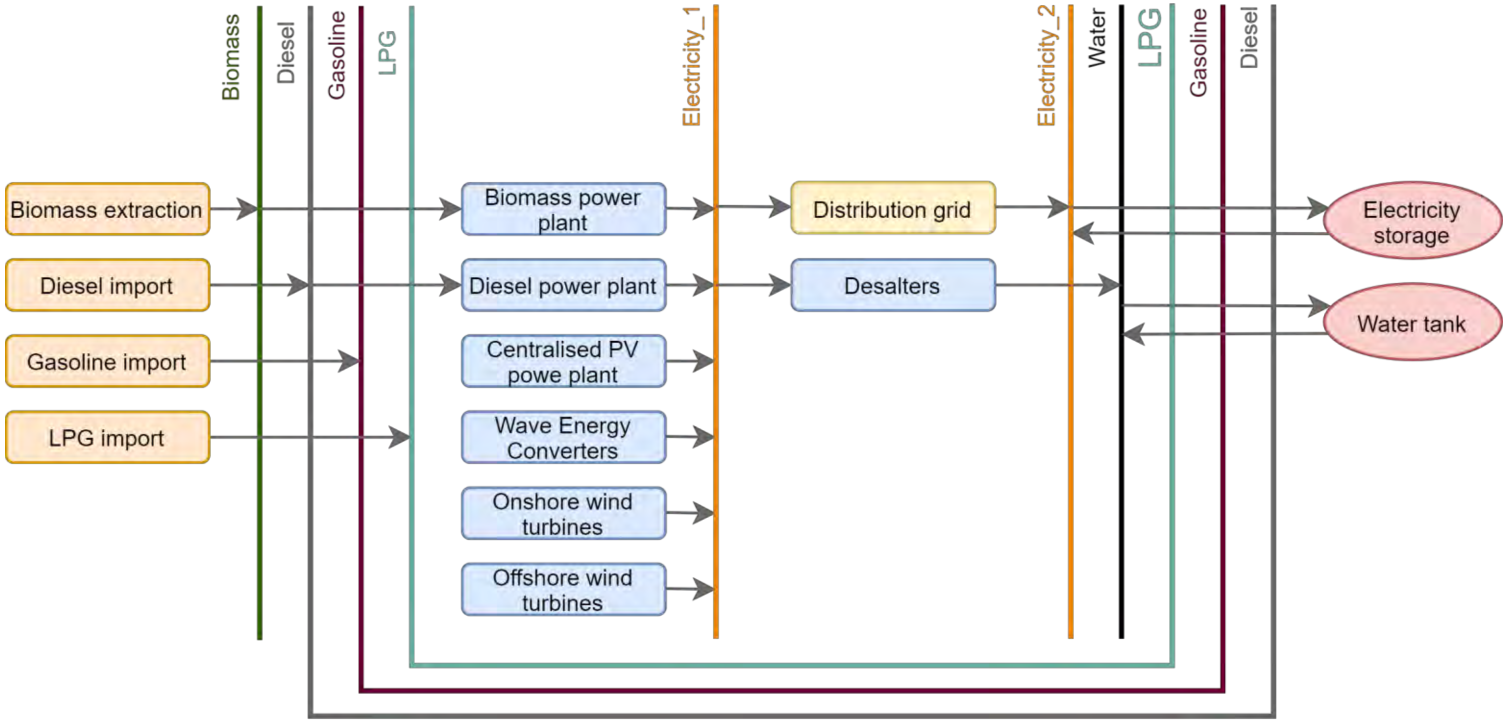
• Howells, Mark, et al. OSeMOSYS: the open source energy modeling system: an introduction to its ethos, structure and development. Energy Policy, 2011, 39.10: 5850-5870.
• Welsch, Manuel; Mentis, Dimitrios; Howells, Mark. Long-term energy systems planning: accounting for short-term variability and flexibility. 2014.

Model inputs and Reference Energy System

CASE STUDY
Pantelleria island



- Data on energy **import and distribution, time-series on energy production and final consumption**
- Technological specifications and **renewables conversion systems models**
- **Yearly time-series of Renewable Energy Sources availability**
- **Capacity and operation constraints** related to environmental and landscape regulations
- Current costs and their future projections



Scenarios and results (1/2)

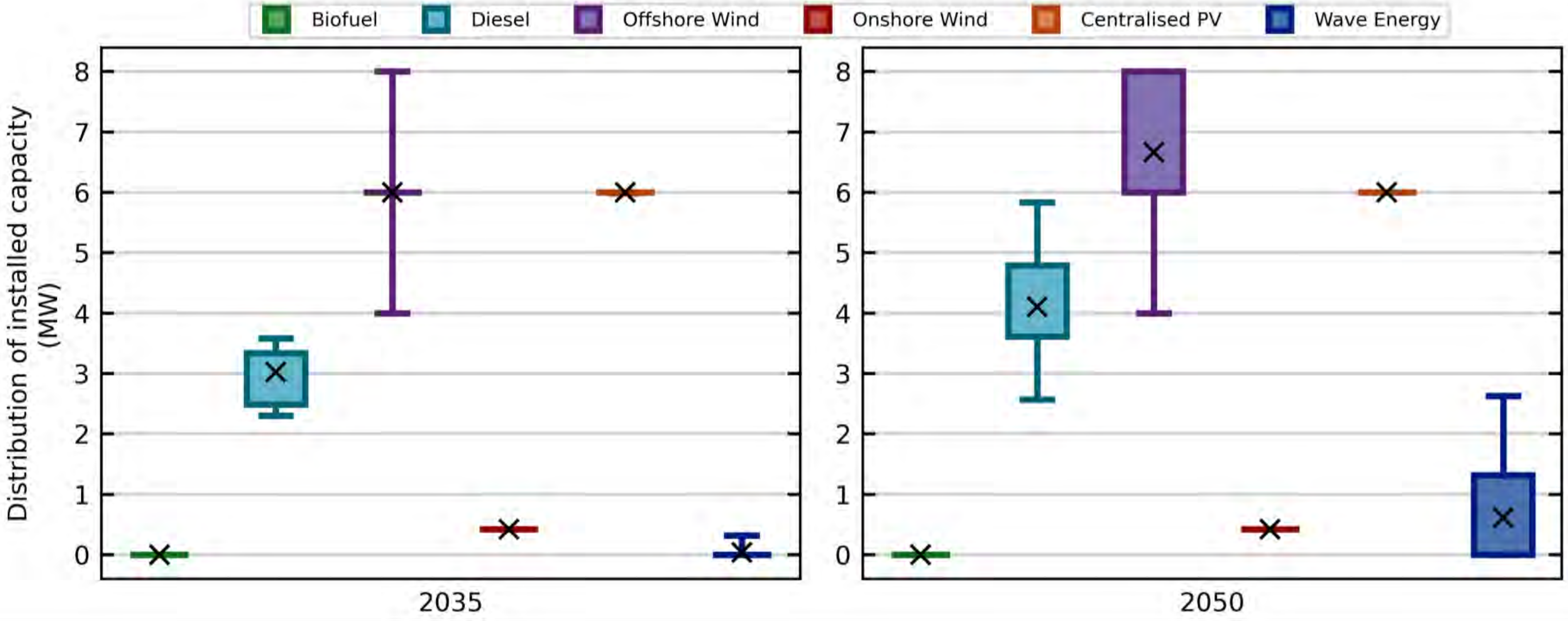
3 distributed photovoltaic evolution trends (Low PV, Medium PV, High PV)
3 Electric Vehicles diffusion schemes (Low EVs, Medium EVs, High EVs)

- Key variables for the evolution of the energy demand
- Can be influenced by public policies
- Different levels of citizens engagement

9 Policy Scenarios + Business As Usual (BAU) reference scenario

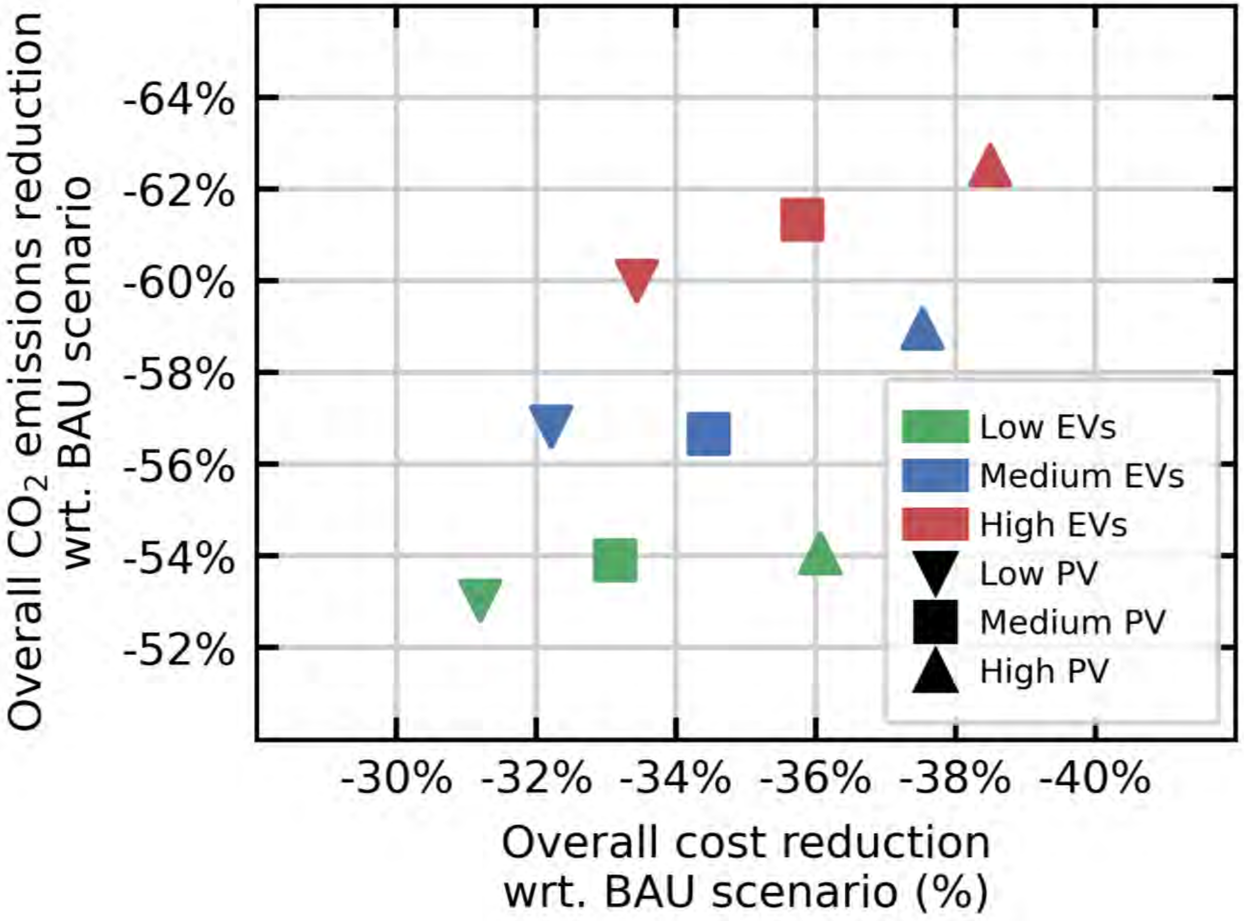
Techno-economic optimisation for the identification of the optimal technology mix for each scenario

Boxplot of installed capacities

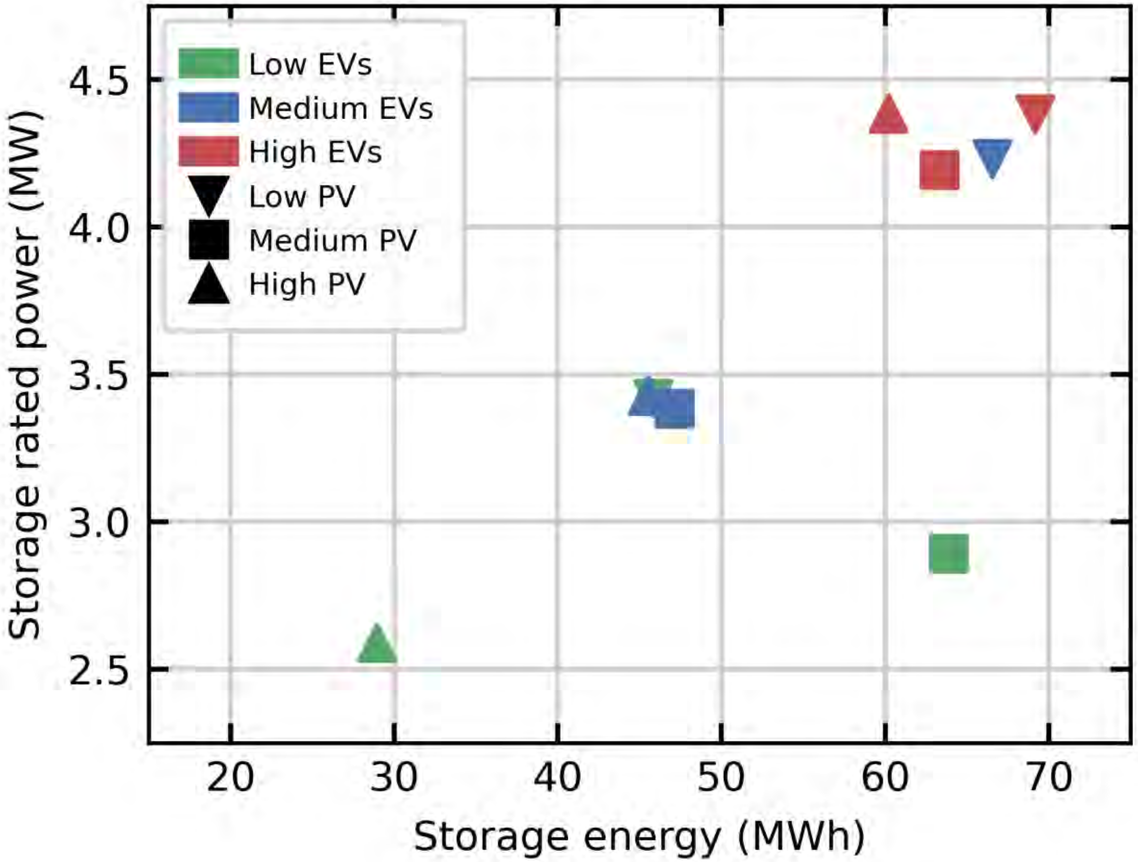


Scenarios and results (2/2)

Scatter plot CO_2 emissions vs overall cost reduction



Scatter plot of main storage systems characteristics



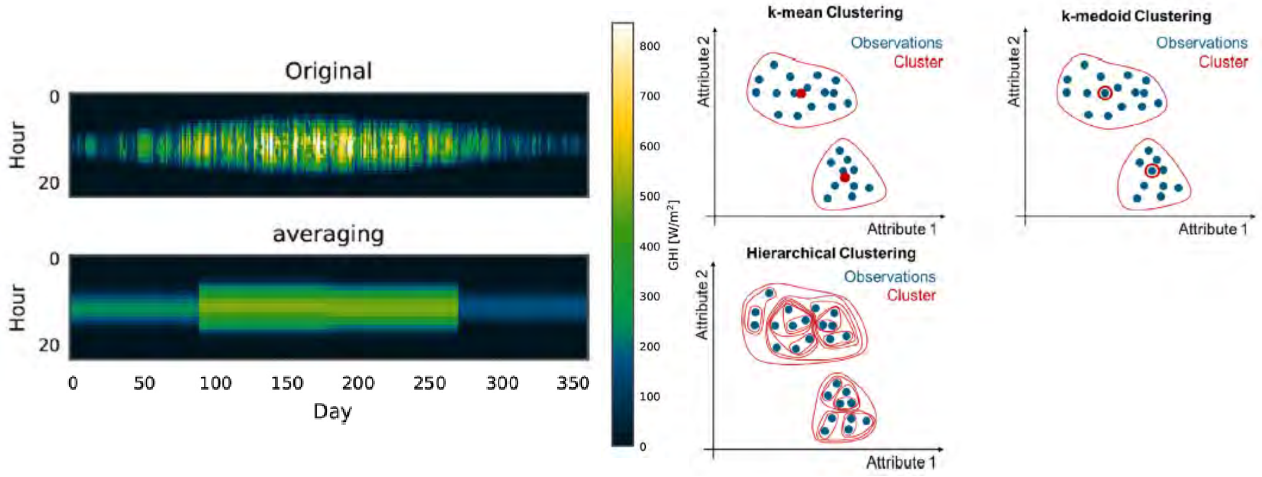
Time-slices

- Each year is described through **representative time periods** known as time-slices
- The overall # of equations depends on:
  - # of time-slices
  - # of years

→ Influence on the **computational burden** and **solvability** of the problem

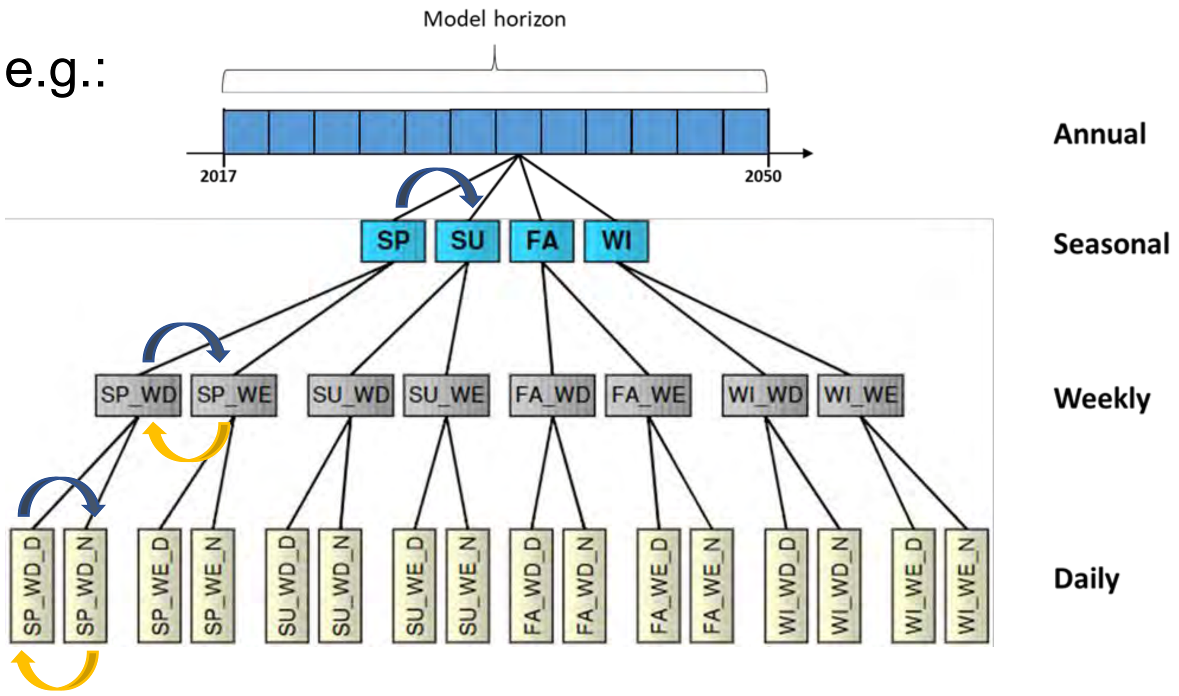
Unordered time-slices

It is a grouping of the time-series into representative time periods
e.g.:
1-year hourly GHI profile, 4x24h time-slices



Temporally ordered time-slices

e.g.:



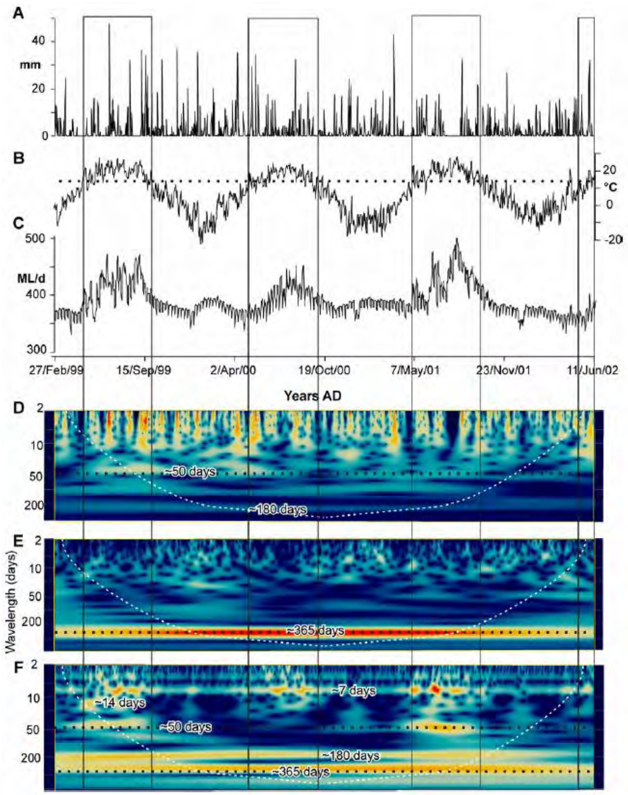
- Renaldi, Renaldi, and Daniel Friedrich. "Multiple time grids in operational optimisation of energy systems with short-and long-term thermal energy storage." Energy 133 (2017): 784-795.
- Gabrielli, Paolo, et al. "Optimal design of multi-energy systems with seasonal storage." Applied Energy 219 (2018): 408-424.

Looking for a novel approach for defining time-slices

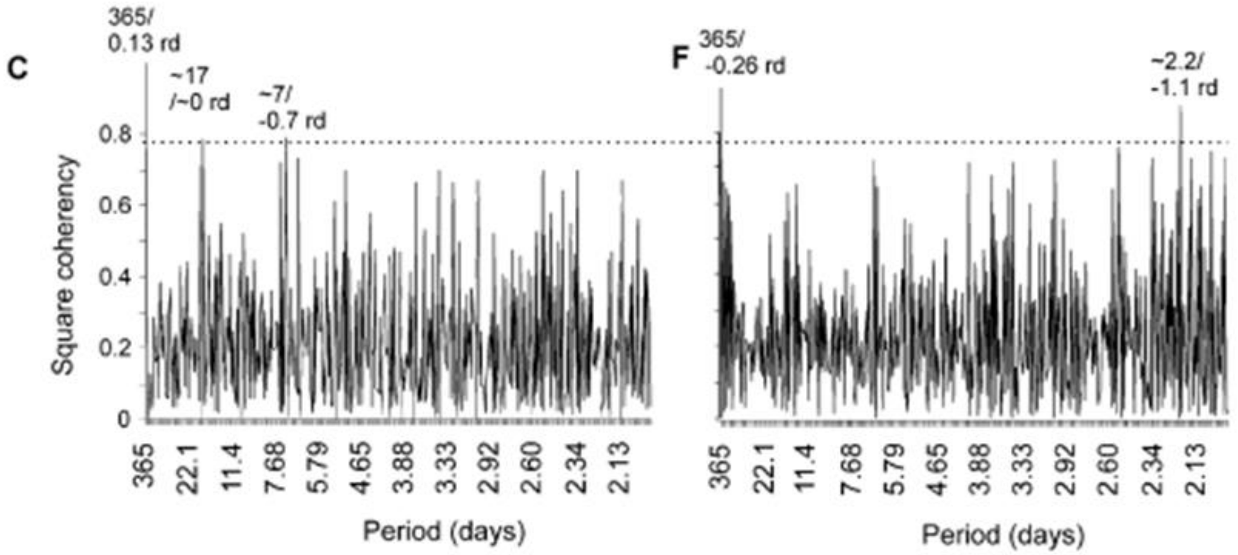
- The **optimal choice of time-slices** is a key factor for accurately capturing the dynamics of the energy system and its components
- From literature study, no specific **supporting tool** seems to be normally used in the selection of time-slices
- Some possible approaches can be derived from **spectral analysis**

Wavelet analysis

- A: daily total precipitation [mm/d]
- B: daily mean temperature [°C]
- C: urban water demand [ML/d]
- D: wavelet scalogram of A
- E: wavelet scalogram of B
- F: wavelet scalogram of C



Cross-spectral analysis



- C: urban water demand VS mean temperature
- F:urban water demand VS total precipitation

- Jurasz, Jakub, et al. A review on the complementarity of renewable energy sources: Concept, metrics, application and future research directions. Solar Energy, 2020, 195: 703-724
- Adamowski, Jan, Kaz Adamowski, and Andreas Prokoph. "A spectral analysis based methodology to detect climatological influences on daily urban water demand." *Mathematical Geosciences* 45.1 (2013): 49-68.

Summary and workplan

Summary

- Python-Pyomo version of OSeMOSYS was studied and integrated with:
  - **Novel equations for storage and short-term** stability
  - A **new user-friendly scenario configurator**
- An OSeMOSYS-based energy model was built for the case study Pantelleria and a set of future scenarios related to **technological diffusion and evolution** was developed and analysed

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Workplan

- Combination with **models of renewable energy conversion systems** (WECs, offshore wind turbines) → optimal design for system integration
- Development of a support tool for the identification of the **most suitable set of time-slices** in view of the different time-series (power consumption and power production from energy conversion devices)
- Addition in the OSeMOSYS-based model of further equations for **short-term dynamics consideration**