The Role of Sector Coupling in Planning the Transition of a Smart Energy Island

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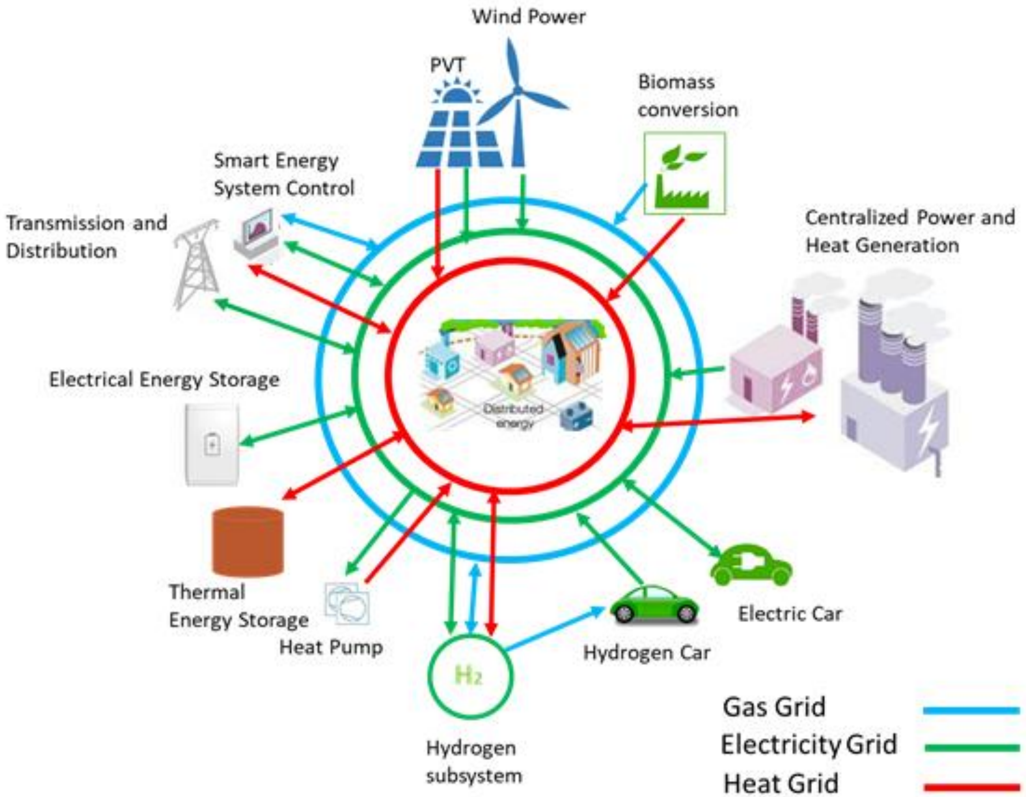
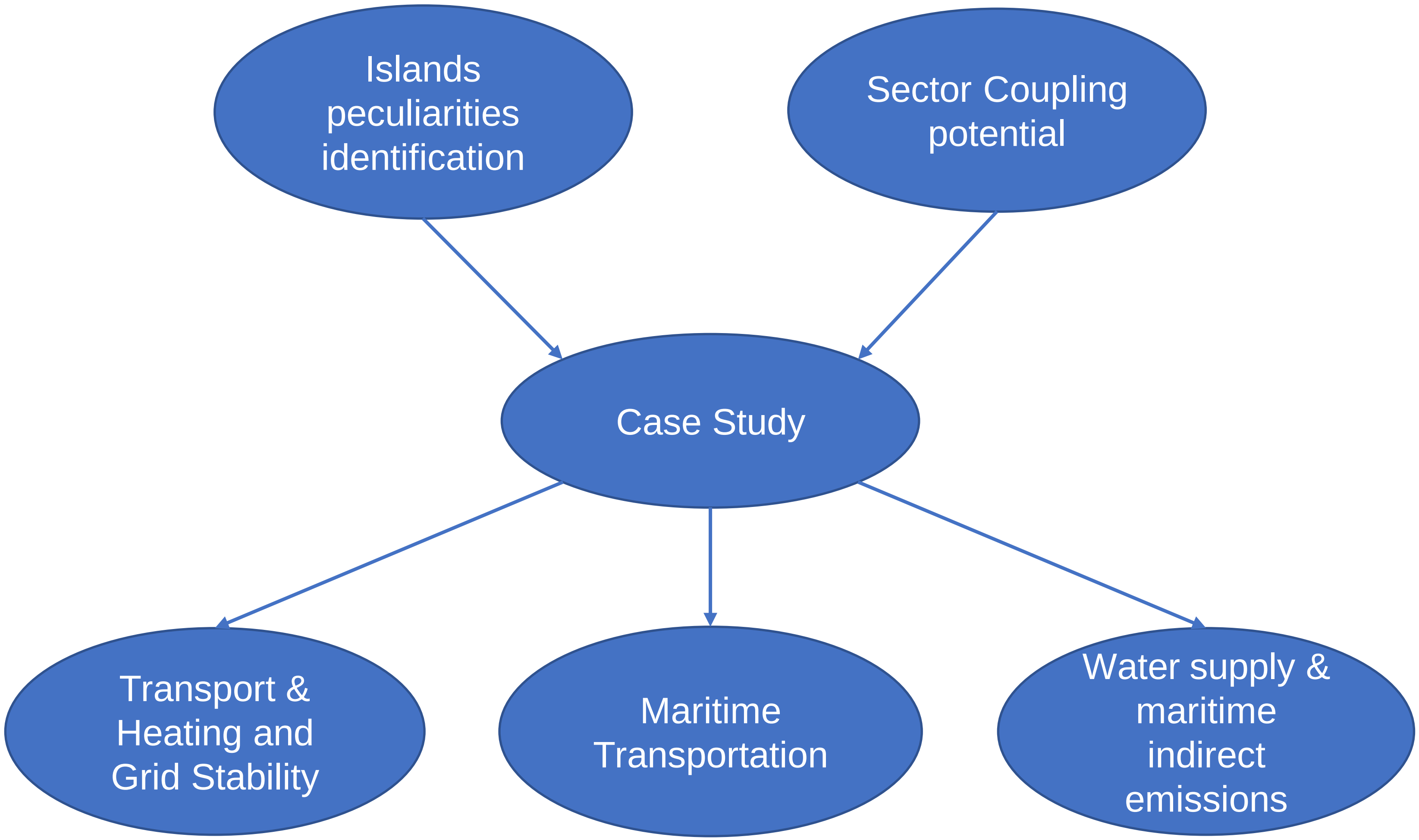
Introduction



Islands are lighthouses to test innovative solutions with high Renewable Energy Source (RES) penetration

This transition is not a trivial task; Variable RES are already causing technical problems making **grid flexibility** a key topic and drawing attention to concepts such as **Demand Response** and **Sector Coupling**.

Energy planning and modelling are essential to plan for an effective transition.


Islands peculiarities identification
Sector Coupling potential
Case Study
Transport & Heating and Grid Stability
Maritime Transportation
Water supply & maritime indirect emissions

Island peculiarities

- High **seasonal variations** due to high touristic fluxes that leads to **systems/plants oversizing**

- relying on fossil fuel plants with **high cost and emissions**;

- **water supply** is very costly and energy intensive;

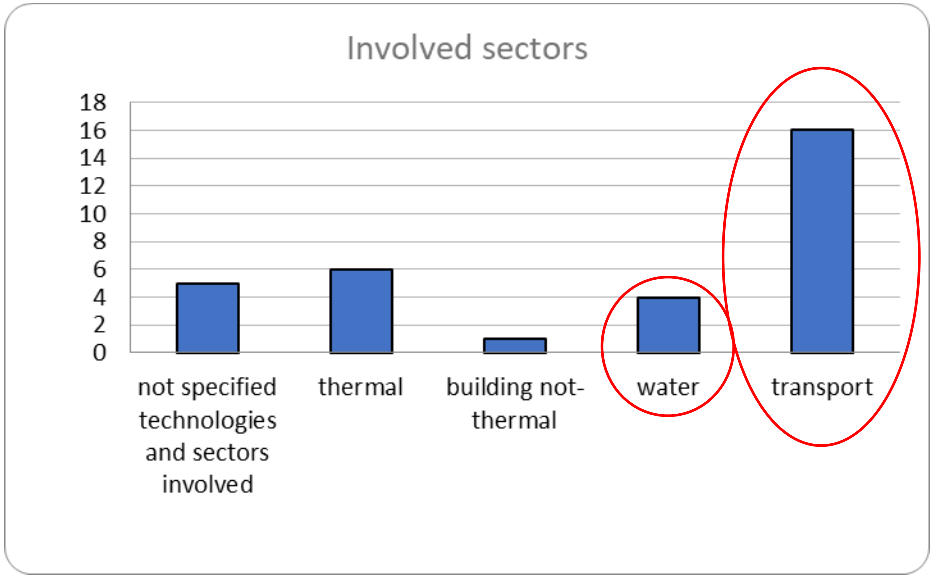
- **maritime transportation** can cover over 60% of whole energy consumption and emissions;

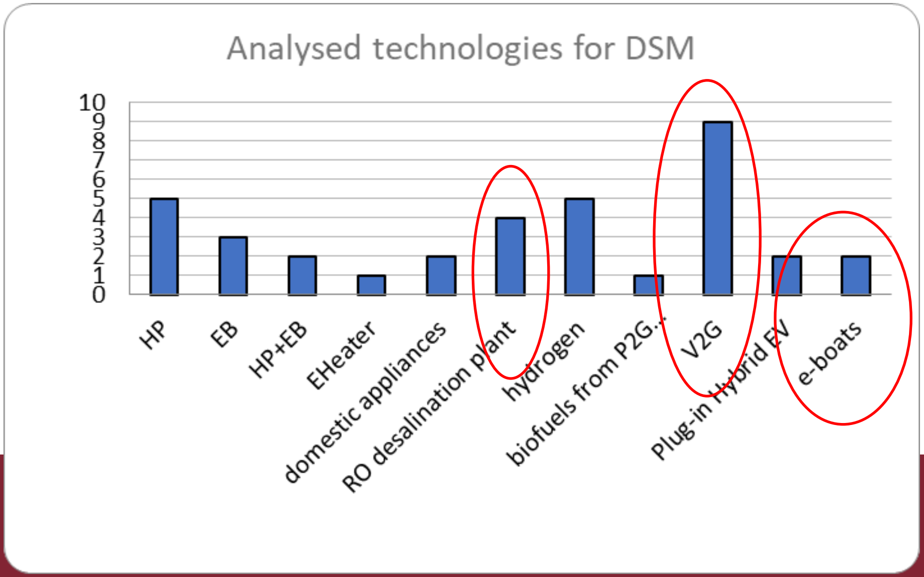
- **indirect emissions due to the maritime transportation** of goods to the island is never considered thus **underestimating the benefits of self-sufficiency and renewables;**

- **low grid stability and reliability** due to little system inertia.

Sector Coupling Potential

- Transport sector is the most analysed with **V2G** but **stability issues are never considered**
- **Maritime transportation is not considered often**
- **Water-energy nexus** is rarely studied but **indirect maritime transportation emissions are never considered**





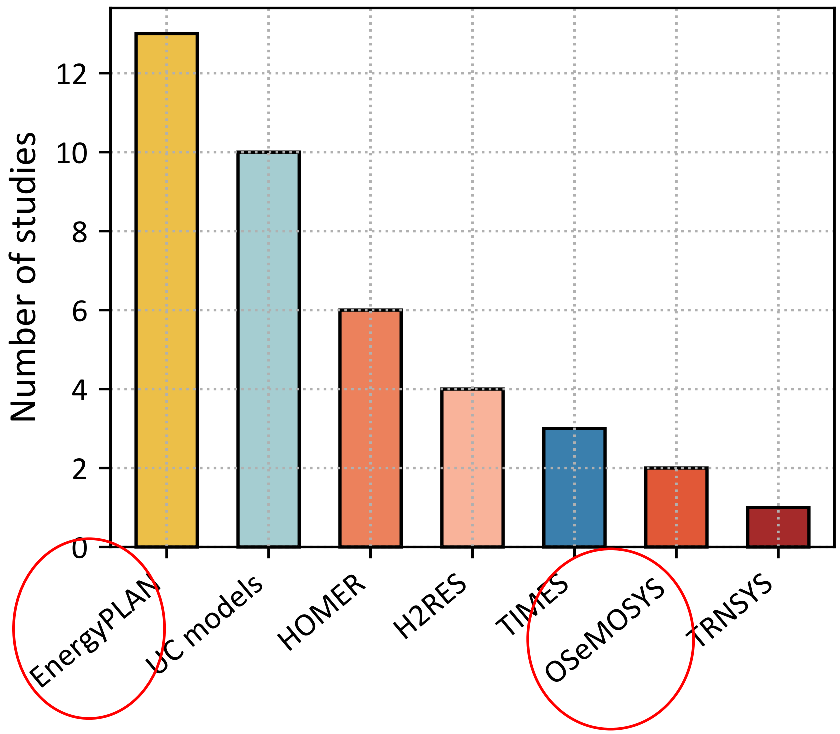
Sector Coupling Potential

EnergyPLAN

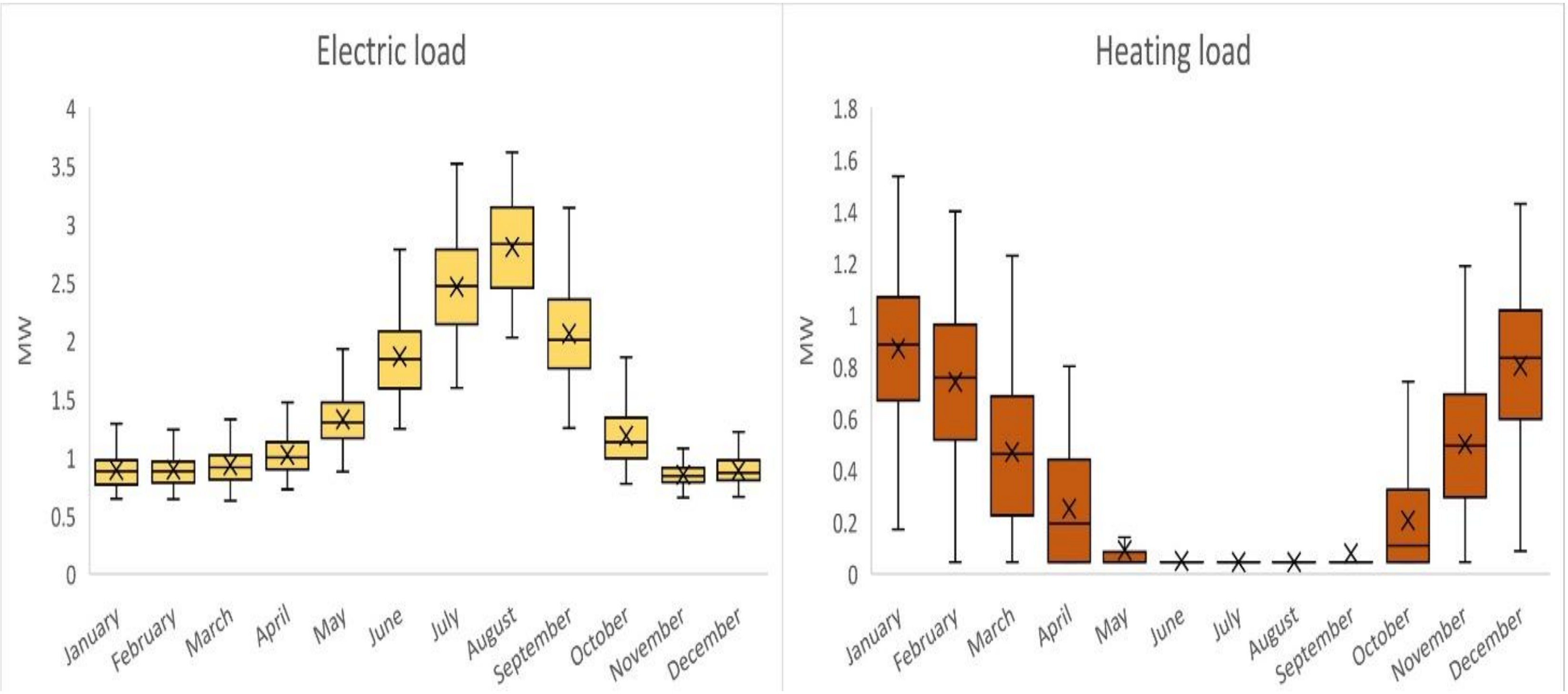
Advanced energy system analysis computer model

OSeMOSYS

Open Source Energy Modelling System



Case study - Favignana



- Electricity consumption of 12.56 GWh/y
- Thermal consumption (LPG) equal to 3.4 GWh/y
- Maritime passengers transportation consumes 57.23 GWh/y
- 7 diesel generators = 12 MW
- Residential PV overall peak power = 170 kWp (Max PV power = 18 MW)

Transport and Heating

Research questions & Novelty:

- *What is the impact of electrification of Transport & Heating sector on the energy system?*

- *How is the grid flexibility impacted?*

- *Do results change when considering the grid stability at planning stage?*

A **multi-objective optimisation** algorithm has been used that is the EPLANopt model.

Methods - EPLANopt

The **EPLANopt** model merges a Multi-objective Evolutionary Algorithm (MOEA) with the EnergyPLAN model.

The dispatching **equality constraints** of matching energy production and demands are embedded in **EnergyPLAN**.

$$Optimisation\ function \qquad \min_{x} \begin{bmatrix} \Delta Total\ annual\ costs \\ \Delta CO_2\ emissions \end{bmatrix}$$

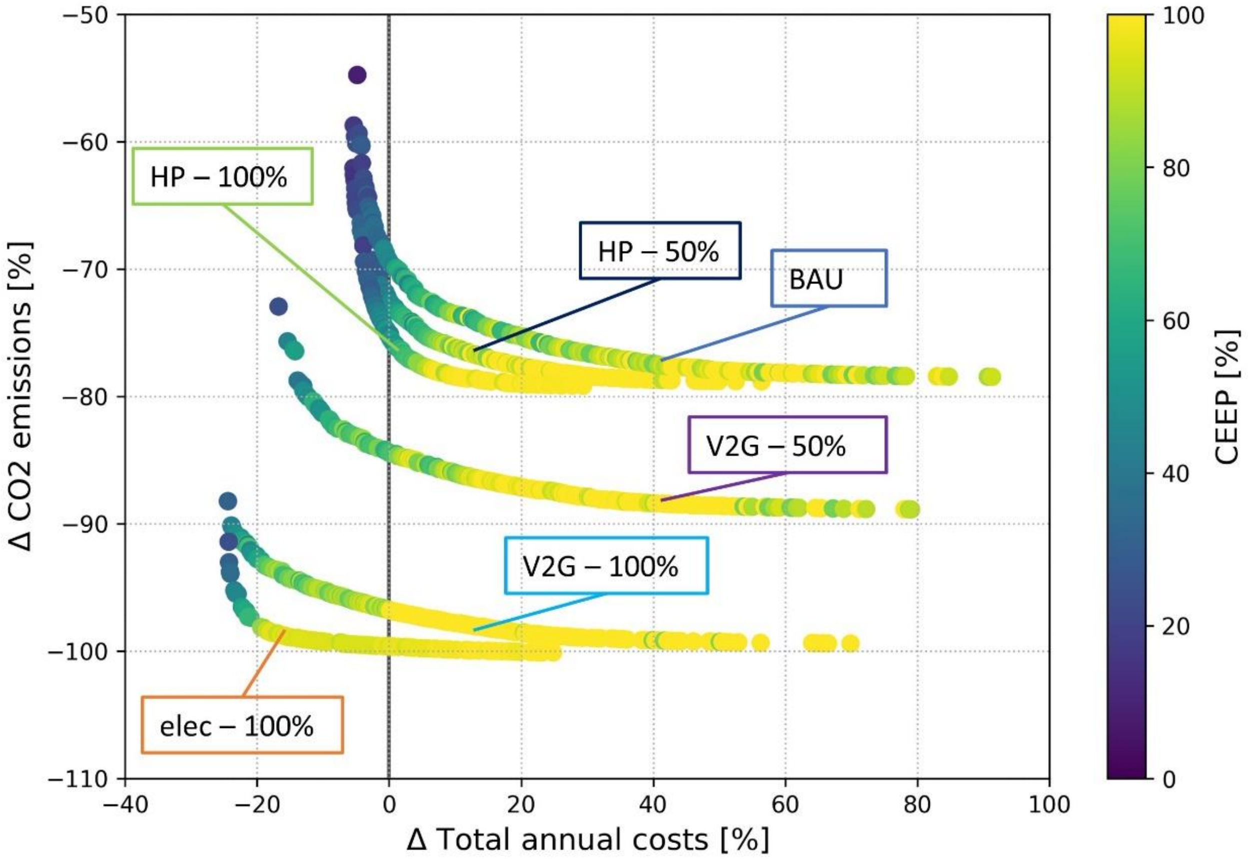
$$Subject\ to\ constraints \qquad Current\ value < x_i < Maximum\ value\ i = 1, 2, 3$$

Optimised variables:
1) PV ; 2) solar collectors; 3) Electricity Energy Storage System (EESS)

A constraint that is relevant to small insular systems that is a threshold on the **Critical Excess Electricity Production (CEEP)** to be less than 5% of overall electricity consumption.

Results – Sector coupling potential

BAU: no sector coupling;
HP – 50%: 50% of thermal demand is covered by HPs;
HP – 100%: entire thermal demand is covered by HPs;
V2G – 50%: 50% of transport is covered by EVs enabled for V2G;
V2G – 100%: entire transport is covered by EVs enabled for V2G;
elec – 100%: both the transport and the heating sectors are fully electrified.



Maritime Transportation

Research Questions & Novelty:

- *What is the optimal technology to decarbonise the maritime transport sector?*
- *Should the decarbonisation of the maritime sector be a priority?*
- *What are the optimal steps that should be previously made to make the decarbonisation of the maritime transport sector?*

Two different technologies are analysed, namely **Battery Electric Ferries** (BEFs) and **Fuel Cell Electric Ferries** (FCEFs).

Other than the maritime transport, this paper will analyse the optimal capacity of i) Photovoltaic (PV) plants (both residential and large scale), ii) Battery Energy Storage (BES), iii) Heat Pumps (HPs) and iv) Solar Thermal (ST) collectors.

Methods – EPLANopt MAC

EnergyPLAN

Advanced energy system analysis computer model

- **Deterministic**
- Designed for the analysis of energy systems with **high degrees of** RES
- High **temporal resolution** of one **hour** to adequately reflect the fluctuations in the various RES
- EnergyPLAN considers the **integration** of different **sectors** of any energy systems.
- Possibility to launch it from command prompt line and run serial simulations.

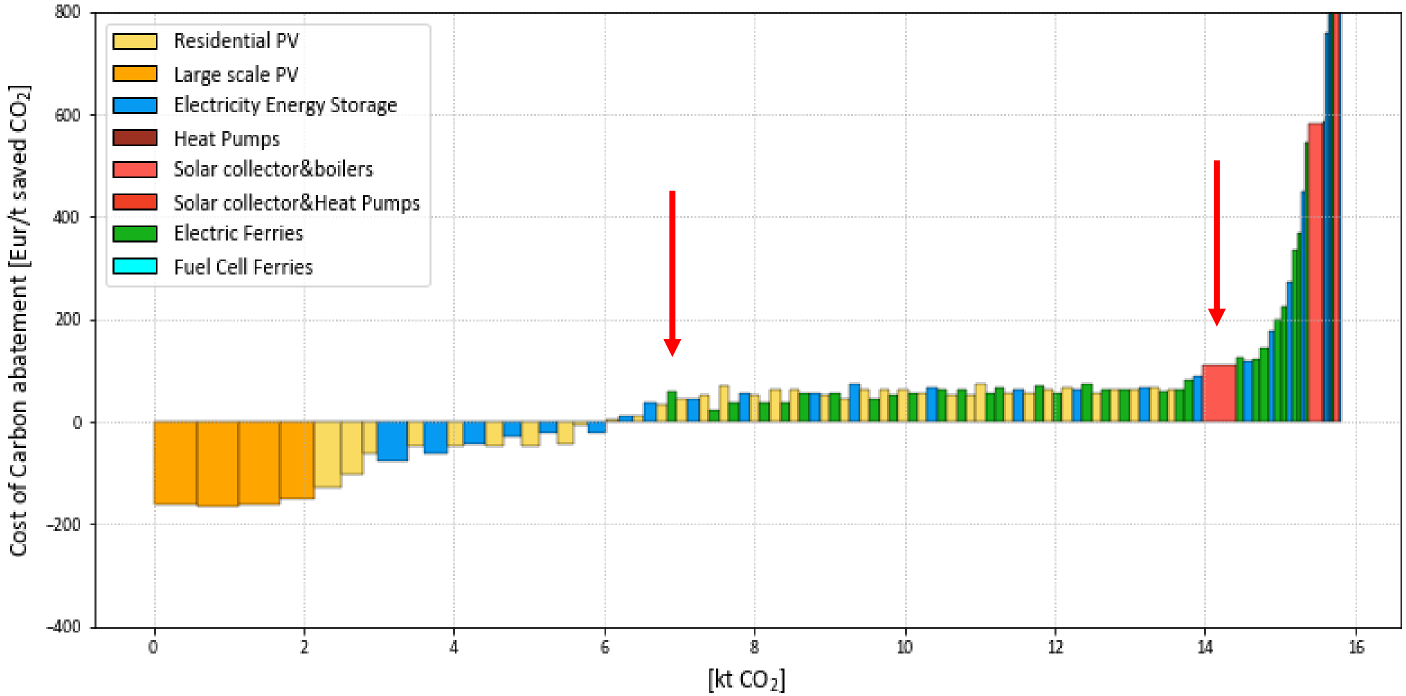
- **Brute force optimization algorithm** to **minimise** the **overall annual costs**
- **Cost effectiveness indicator** as **objective function**

$$Cost_{effectiveness} = \frac{(Cost_i - Cost_{ref})}{(CO_{2,i} - CO_{2,ref})}$$

- Definition of the **constraints** given by the incremental value for each step and maximum potentials

python

Results



- **Priority should clearly be given to new PV installation**;
- a **negative cost per ton of CO_2** is obtained until the overall **PV** and **BES** capacity are equal to **6.5 MW and 15 MWh** (**-10% emissions** than baseline);
- when an overall PV capacity of 7.5 MW and a BES capacity of 20 MWh is reached, investment in BEFs become the preferrable, thus cheaper, solution.

Water sector & indirect emissions

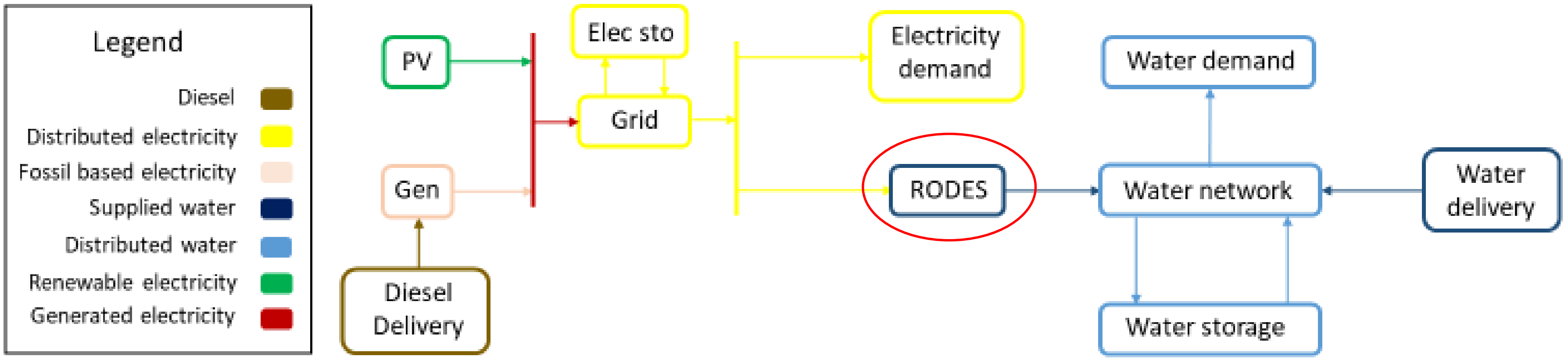
Research questions & novelty:

- *What is the best way to **supply water** to the island?*
- *Does considering the **indirect emissions** of the maritime transport for goods (i.e. water and diesel for power generation) **impacts the optimal solution**?*
- *How does the optimal transition pathway change with different **energy policies**?*
- *What is the trade-off of using different time slices in OSeMOSYS models?*

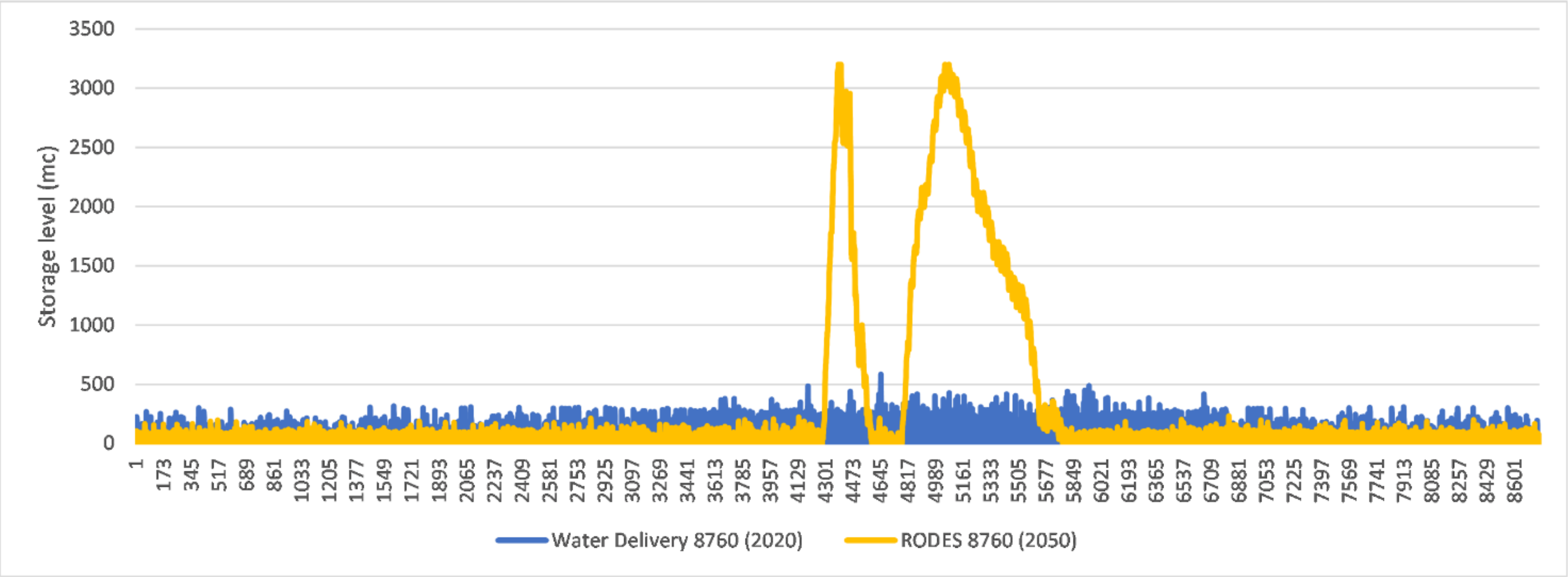
System Layout

“**OSeMOSYS** - Open Source Energy MOdelling SYStem” framework has been used.

Open source, multi-year, single-objective linear optimization with an economic objective

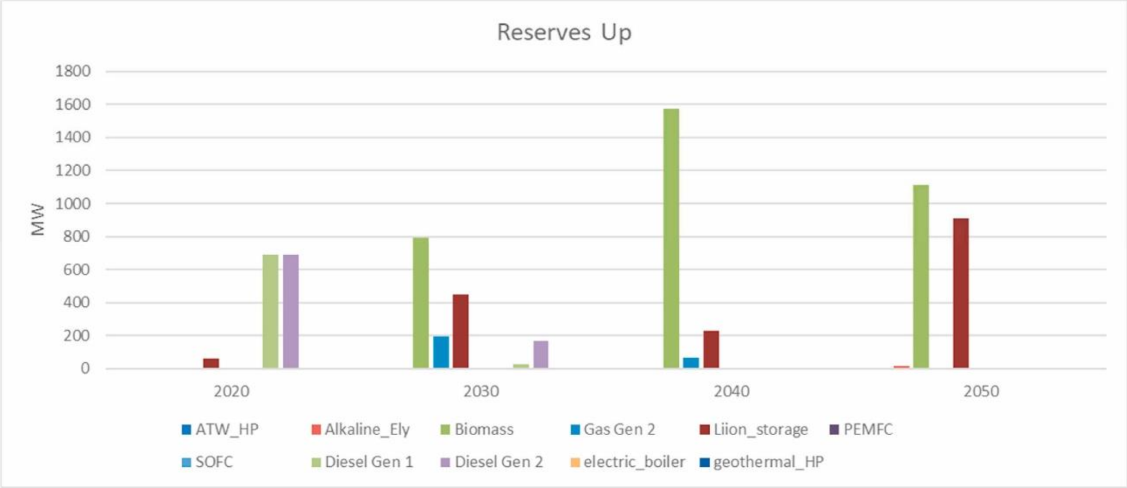


Results – Time Resolution

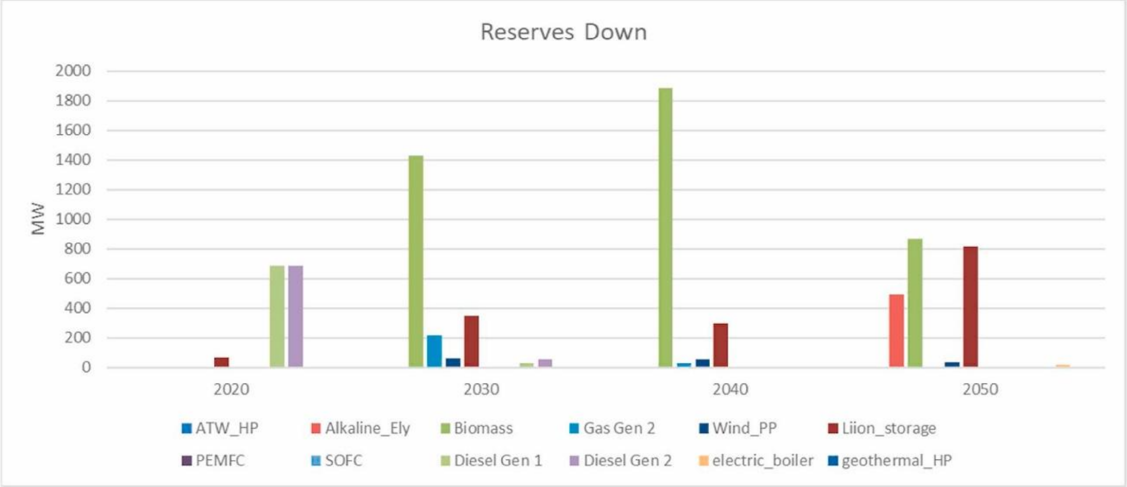


Reserves

- The **major sources of reserves** in the baseline year are the **two diesel generators** and the small Li-ion plant;
- in the next years, **biomass becomes the major reserve supplier**, both up- and downwards followed by Li-ion batteries;
- in 2050, when a **100% RES** share is reached, **biomass and Li-ion batteries supply a comparable amount of reserves** around the 800 MW in the whole year;
- when the 100% RES share is reached the need for **ELY to provide downwards reserves** is evident;
- a negligible amount of downward reserve is provided by EBs in 2050.



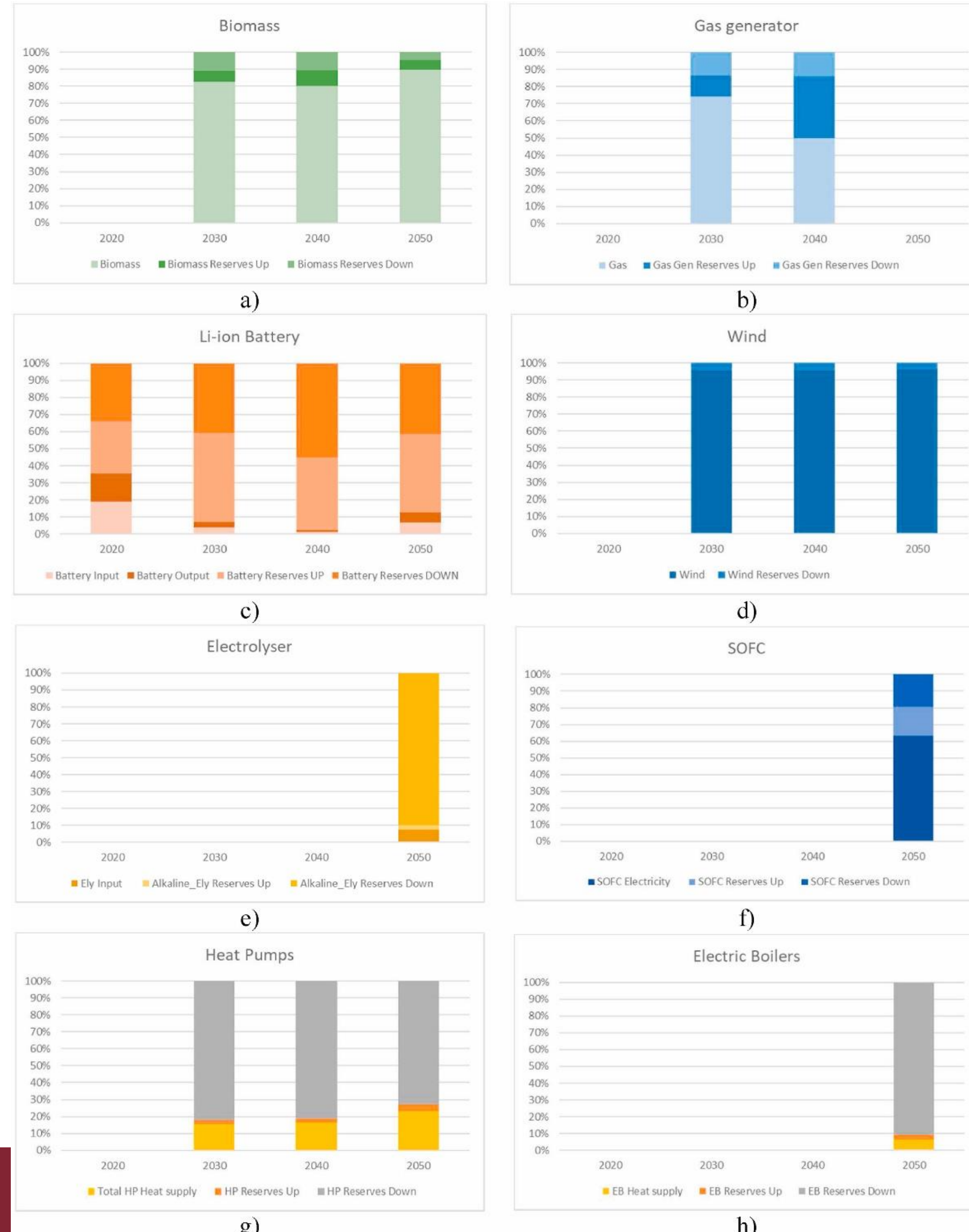
a)



b)

Reserves

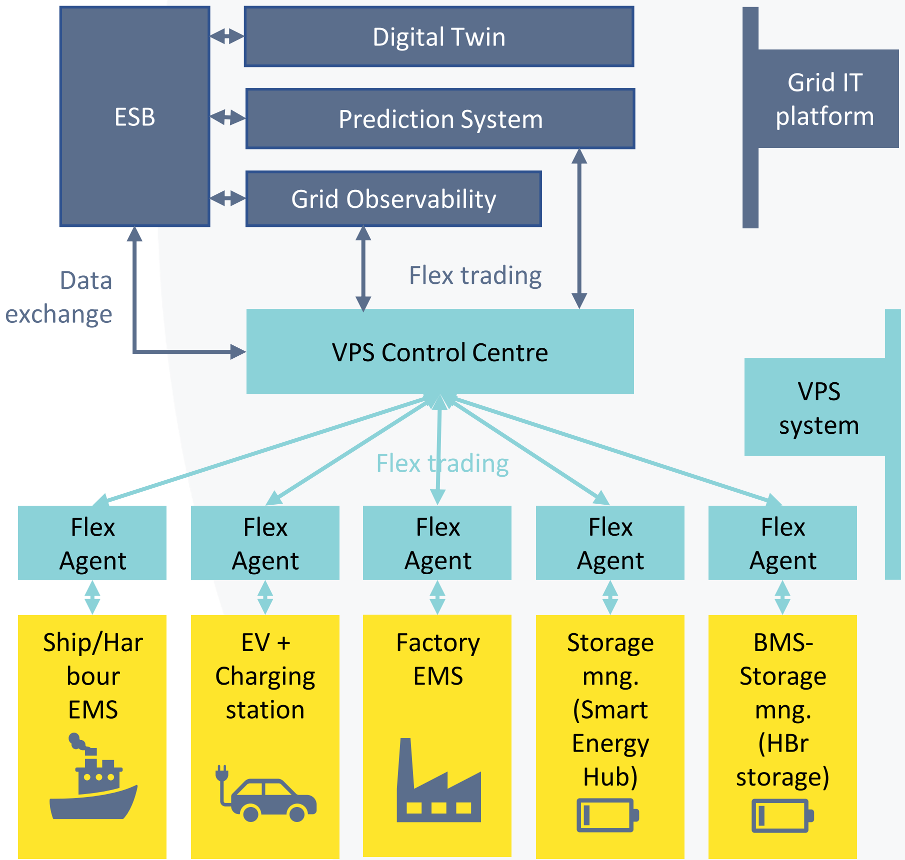
- **Biomass** is **mainly used for electricity production** while also being the biggest reserve provider of the whole energy system.
- gas generator shifts from being mainly an electricity supplier in 2020, then a reserve provider in 2030 and then disappear.
- In 2050, when the 100% RES share target is reached, hydrogen technologies are installed, the **electrolyser's main function is that of a reserve provider for downwards reserve**; while the FC is mainly used as a power generator while also providing both up and down reserve services. Reserve provision might represent the **core business model for ELYs**.
- **Li-ion batteries** have a similar use throughout the whole time-horizon being **mainly a reserve supplier** with a balanced share of up- and down-wards reserve use. From 2030 onwards, when PV and Wind turbines are installed, Li-ion batteries work for almost **85%** of the time as reserve providers.
- Regarding the heating sector technologies, HPs and EBs have different roles in the system. **HPs** are installed in 2030 and are used for **both heating supply and downwards reserves**. Differently than HPs, **EBs** are installed only in 2050 and are used **almost entirely for downwards reserves**.



Solutions

The GIFT solutions to reach these objectives:

- *<u>Grid IT platform</u> for KPI visualisation, geographic visualisation, grid observability, prospective modelling and long-term assessment.*
- *<u>VPS system</u>, a decentralised automatic demand response trading platform, connecting DR providers, intermediaries and DR users that is coupled with <u>Flex Agents</u>, installed at DR providers*
- *<u>Prosumers</u> or smart energy consumers that postpone energy demanding tasks or select alternate sources for energy to reduce the load on the power grid, thus providing flexibility.*

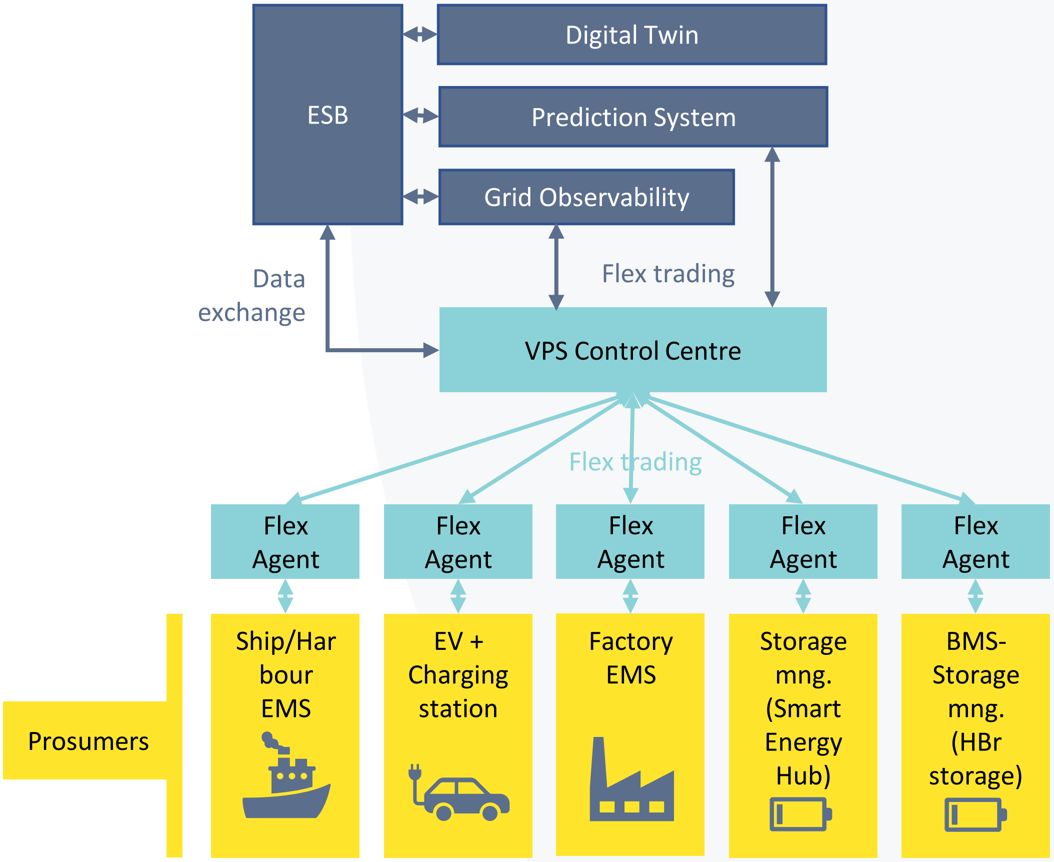


GIFT

Solutions

GIFT prosumers include:

- *Energy Management Systems (EMS):*
  - *Ship/Harbour EMS*
  - *Factory EMS*
- *Electric Vehicle (EV) charging stations*
- *Storage management:*
  - *Smart Energy Hub*
  - *HBr storage*



GIFT

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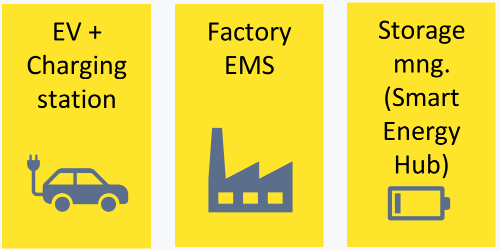
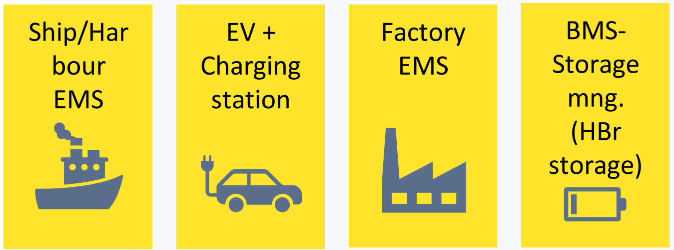
Demonstration

These solutions will be implemented on:

- <u>*Procida Island (IT)*</u>
  - *Small island with grid congestions*
  - *High seasonality of demand (tourism)*
- <u>*Hinnøya Island Cluster (NO)*</u>
  - *Cluster of large and small islands*
  - *Fish farms using diesel generators*

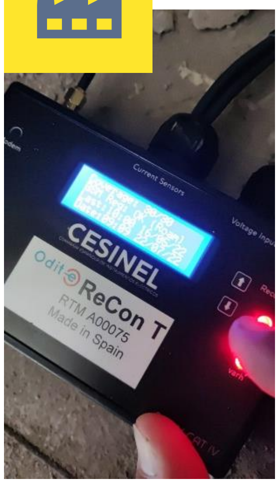




Demonstration - Procida

EV + Charging station

Factory EMS

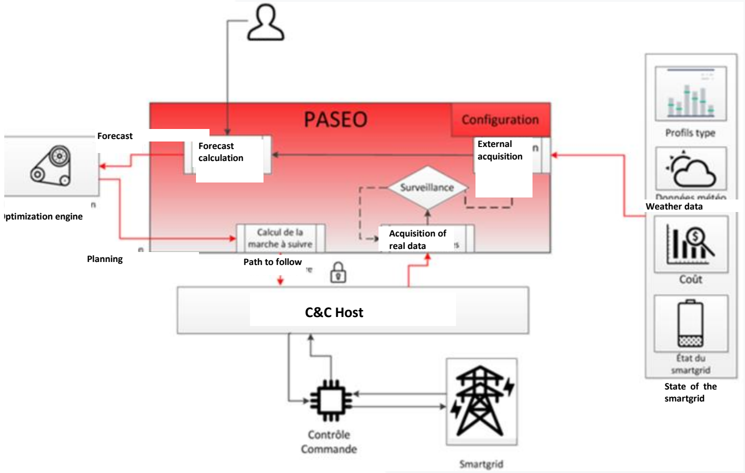


Storage mng. (Smart Energy Hub)

GIFT

Demonstration - Procida

Storage mng. (Smart Energy Hub)



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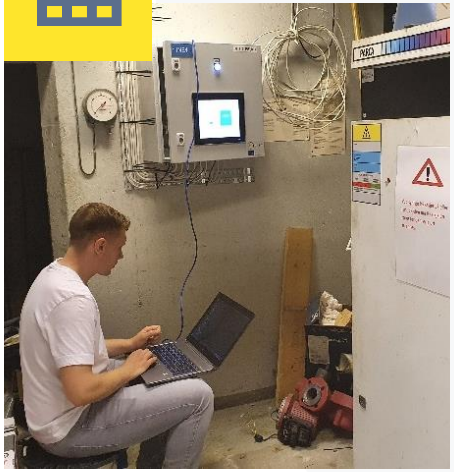
Demonstration - Hinnøya

Ship/Harbour EMS

EV + Charging station

Factory EMS



BMS-Storage mng. (HBr storage)

GIFT

Conclusions

Sector coupling:

- **Maritime transport** must be tackled to reach 40% or more emissions savings, Electric Ferries are preferrable to Hydrogen ones;
- **indirect emissions** for water delivery represents the 18.2% of the overall yearly emissions and cannot be neglected;
- **water storage** is used in summer to provide flexibility to the power sector, but it is not used as a seasonal storage;
- **HPs for heating** purposes do not offer a relevant flexibility potential and ST collectors should be preferred in order to electrify other consumptions given the limited space availability for PV;
- **V2G** would enormously increase the grid flexibility and almost eliminate the need for Electricity Energy Storage;

Modelling:

- it is extremely important to consider the **grid stability at planning stage** since results are hugely affected by it both in terms of CO_2 savings and Total System Cost;
- **time slices** affect both yearly outcomes & pathways trends and even more intra-annual profiles;
- Continental and National **energy policies** must consider also islands systems, a carbon tax would lead to the least overall emissions even if it does not affect the maritime sector.

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Thanks for your attention

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For any further questions,

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