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DIPARTIMENTO DI ENERGIA

Optimization method to obtain marginal abatement cost-curve through EnergyPLAN software

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Problem

Energy system modelling is typically used to find the **best energy mix** and does not provide:

- The **path** to be followed to obtain the predicted **expansion capacity** (and better support policy-makers)
- **Info**rmation on the **competing decision variables** and the reasons why a certain best energy mix is found.

Marginal Abatement Cost (MAC) curves aim at solving these problems improving transparency and supporting policy-makers on the measures implementation sequential order to meet GHG reduction requirements.

However, current methodologies for realizing **MAC curves** presents **limitations** in terms of **sector-coupling** and **time resolution**.

MAC state of art – bottom up models

Model name	Area	Goal Function	Long/Short	Sector	Time resolution
MARKAL UK	England	Maximization of producer and consumer surplus	Long	Transport	6 time-slices
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TIMES_PT	Portugal	Minimum system cost	Long	**Sector-coupling**	16 time-slices
LUSYM	Central western Europe	Operation cost minimization	Short	Power	**Hour**
AIM/Enduse	Global (32 sections)	Minimum system cost	Long & short	**Sector-coupling**	1 time-slices
DNE21+	54 world regions	Discounted total energy system cost minimization	Long	**Sector-coupling**	1 time-slices
GAINS	Annex I countries (36 countries)	Minimization of total system cost	Short	**Sector-coupling**	1 time-slices
TIMES_GECCO	Regional (Gauteng)	Minimization of total system cost	Long	Transport	42 time-slices
MARKAL_GEORGIA	Armenia and Georigia	Minimization of total system cost	Long	Building sector	8 time-slices
OSeMOSYS	Bolivia	Minimization of total system cost	Long	Power	48 time-slices
METER	Korea	Minimization of total system cost	Short	Power	73 time-slices
AIM/Enduse	Korea	Minimum system cost	Short	Residential	
AIM/Enduse	Thailand	Minimum system cost	Short	Industry	
EPLANopt_MAC	Italy	Minimum system cost	Short	**Sector-coupling**	**Hour**

Lack of time resolution with simultaneous sector-coupling

Aim of the work

To create a model to find MAC curves through a robust optimization process

The simulation of the energy system within this model should implement high temporal resolution and sector coupling. In order to achieve that, the optimization model is based on the EnergyPLAN software.

EPLANoptMAC model

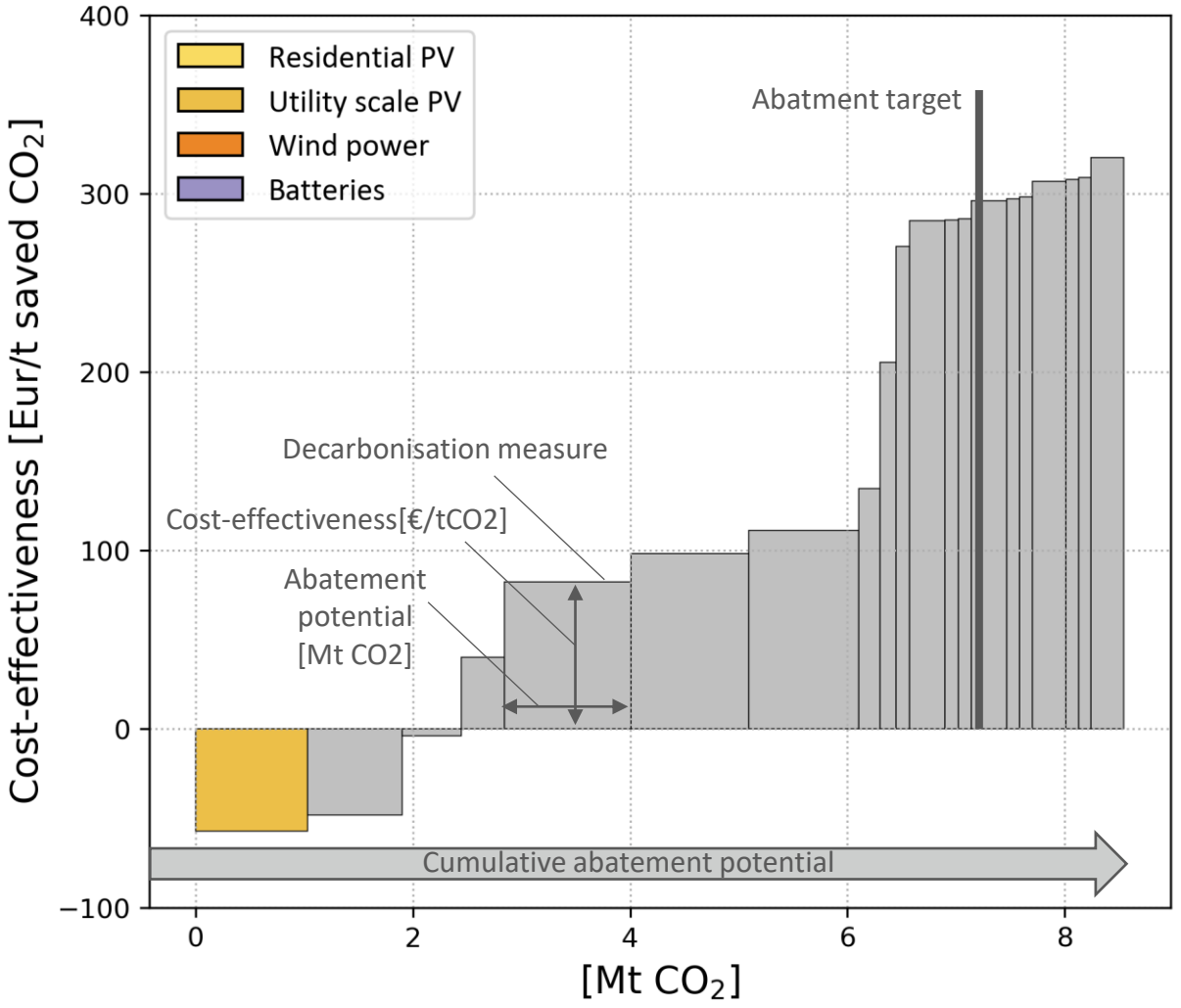
- **Deterministic**, analytically programmed energy system **simulation model**
- Particularly designed for the analysis of energy systems with **high degrees of renewable** energy sources (RES)
- It simulate one-year periods with a **temporal resolution** of one **hour** to adequately reflect the fluctuations in the various RES
- EnergyPLAN considers the **integration** of three primary **sectors** of any national energy systems.
- The results developed using EnergyPLAN are constantly being published within academic journals.
- Possibility to launch it from command prompt line. And so the possibility to create an external code in order to run serial simulations.

- **Brute force optimization algorithm** to select the sequential order of the decision variables **minimizing** the **overall annual costs**
- Definition of the **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 for each decision variables and their maximum potentials

EPLANoptMAC model



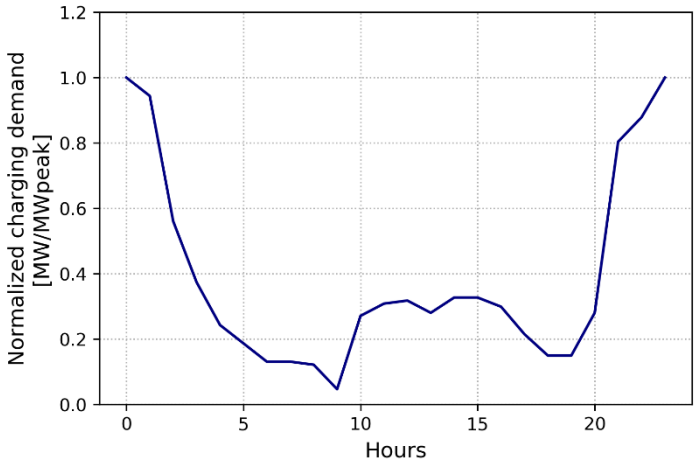
	Utility scale PV	Wind power	Residential PV	Batteries
step 1	+1 GW	+1 GW	+1 GW	+1 GWh
step 2	+1 GW	+1 GW	+1 GW	+1 GWh
step 3	+1 GW	+1 GW	+1 GW	+1 GWh
step 4	+1 GW	+1 GW	+1 GW	+1 GWh
step 5	+1 GW	+1 GW	+1 GW	+1 GWh
step 6	+1 GW	+1 GW	+1 GW	+1 GWh
step 7	+1 GW	+1 GW	+1 GW	+1 GWh
step 8	+1 GW	+1 GW	+1 GW	+1 GWh
step 9	+1 GW	+1 GW	+1 GW	+1 GWh
step 10	+1 GW	+1 GW	+1 GW	+1 GWh
step 11	+1 GW	+1 GW	+1 GW	+1 GWh
step 12	+1 GW	+1 GW	+1 GW	+1 GWh
step 13	+1 GW	+1 GW	+1 GW	+1 GWh
step 14	+1 GW	+1 GW	+1 GW	+1 GWh
step 15	+1 GW	+1 GW	+1 GW	+1 GWh
step 16	+1 GW	+1 GW	+1 GW	+1 GWh
step 17	+1 GW	+1 GW	+1 GW	+1 GWh
step 18	+1 GW	+1 GW	+1 GW	+1 GWh
step 19	+1 GW	+1 GW	+1 GW	+1 GWh
step 20	+1 GW	+1 GW	+1 GW	+1 GWh

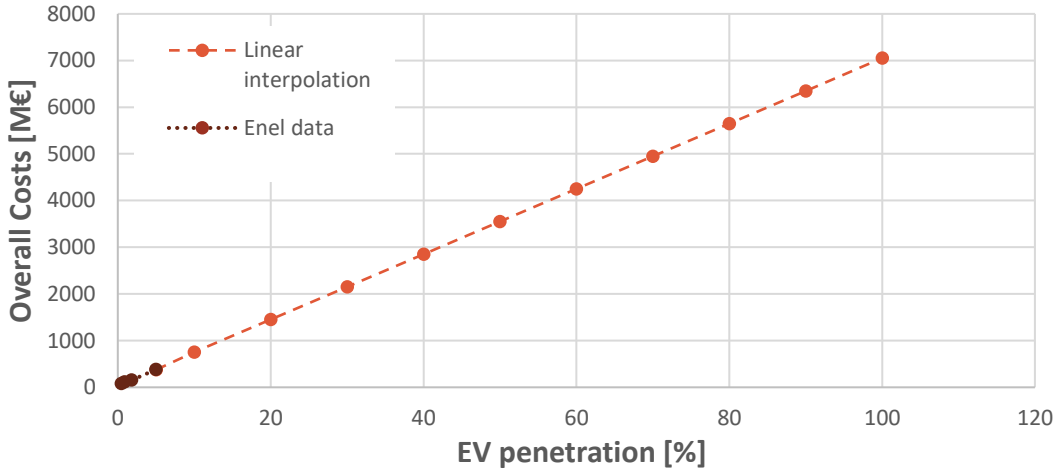
Italian case study

Baseline 2015

Sector	*Data*	*Source*
Electricity	Installed capacity for RES	GSE
	Hourly distributions for RES	Terna, GSE
	Installed capacity for other technologies	Terna
	Electricity demand	Terna, HRE
Heat	Generation and consumption data	HRE
Mobility	Consumption data	HRE
	BEV demand and charge profile	RSE

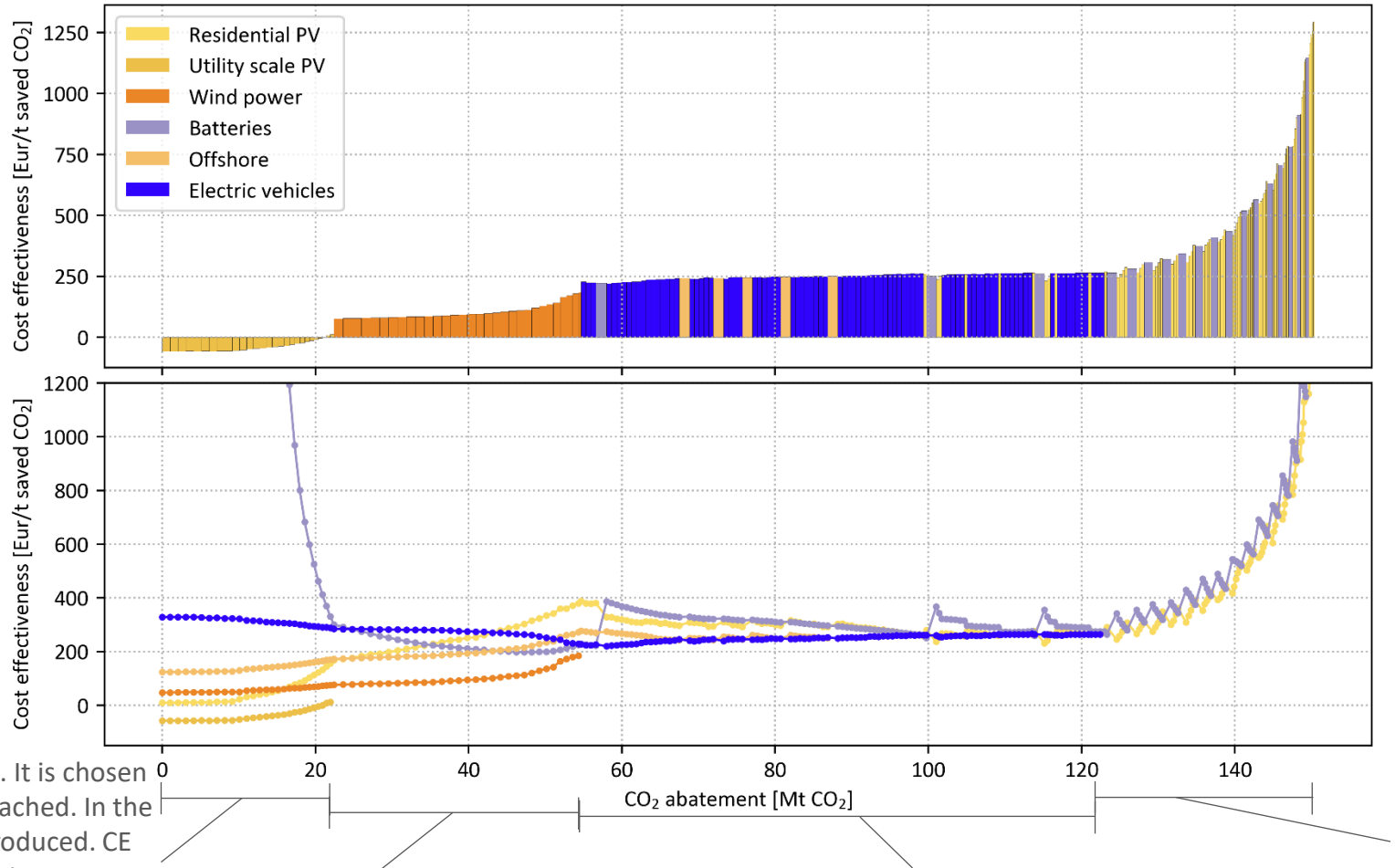
Starting from the Heat Roadmap Europe the baseline of the Italian energy system has been created adding some modifications with respect to HRE.





Application of the MAC curve to the current state of the energy system

Results - Cost effectiveness trends



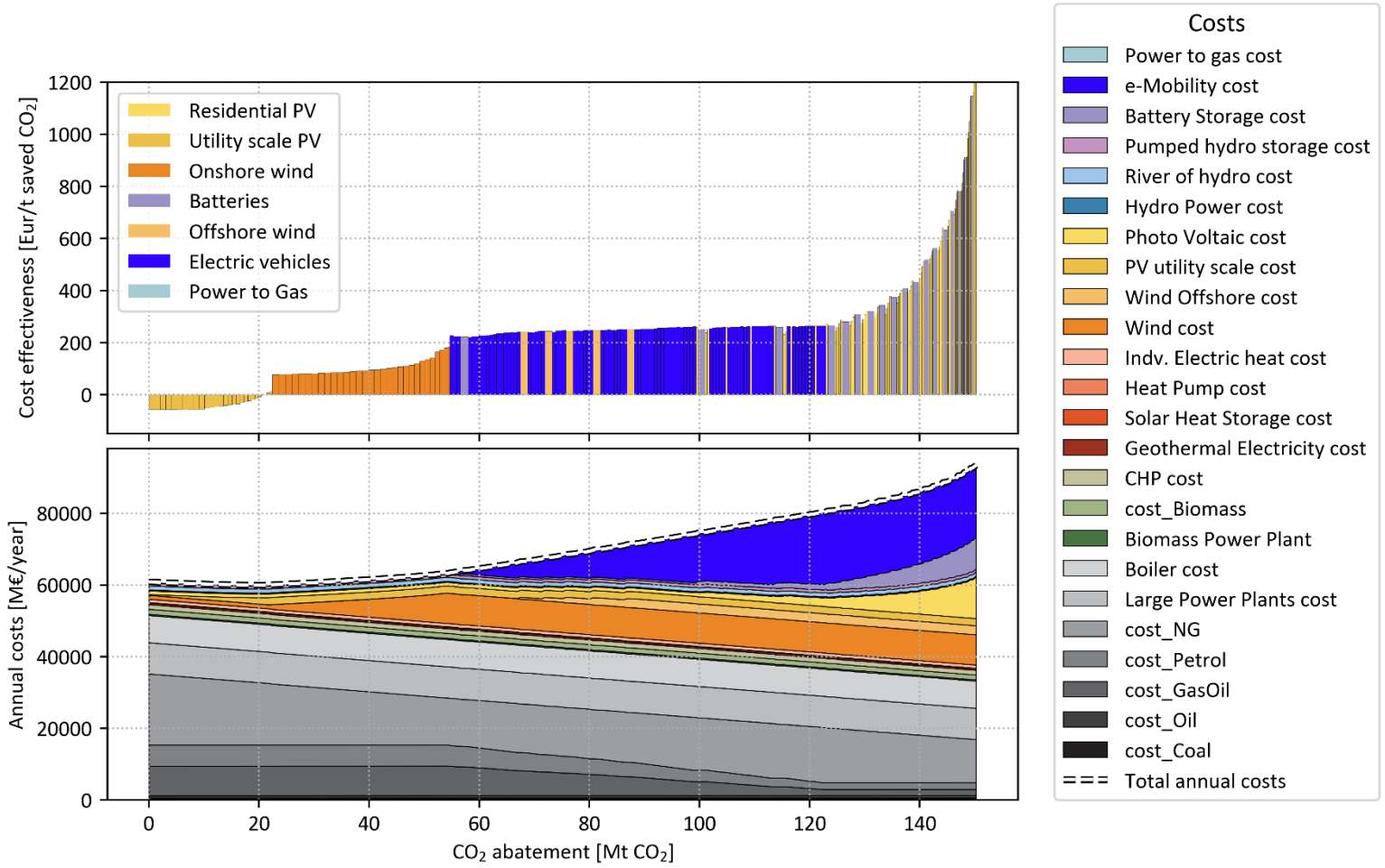
Utility scale PV has the lowest CE. It is chosen until the maximum potential is reached. In the meanwhile overgeneration is produced. CE from other generation sources increase. Residential PV CE increases with a similar trend due to the same shape of the generation profile

Wind power has the lowest CE (Once US PV has reached its potential). Overgeneration rises and CE of storage decreases.

Once overgeneration from RES occurs the introduction of electric mobility is the measure with the lowest CE. With also some installation of offshore wind power and batteries

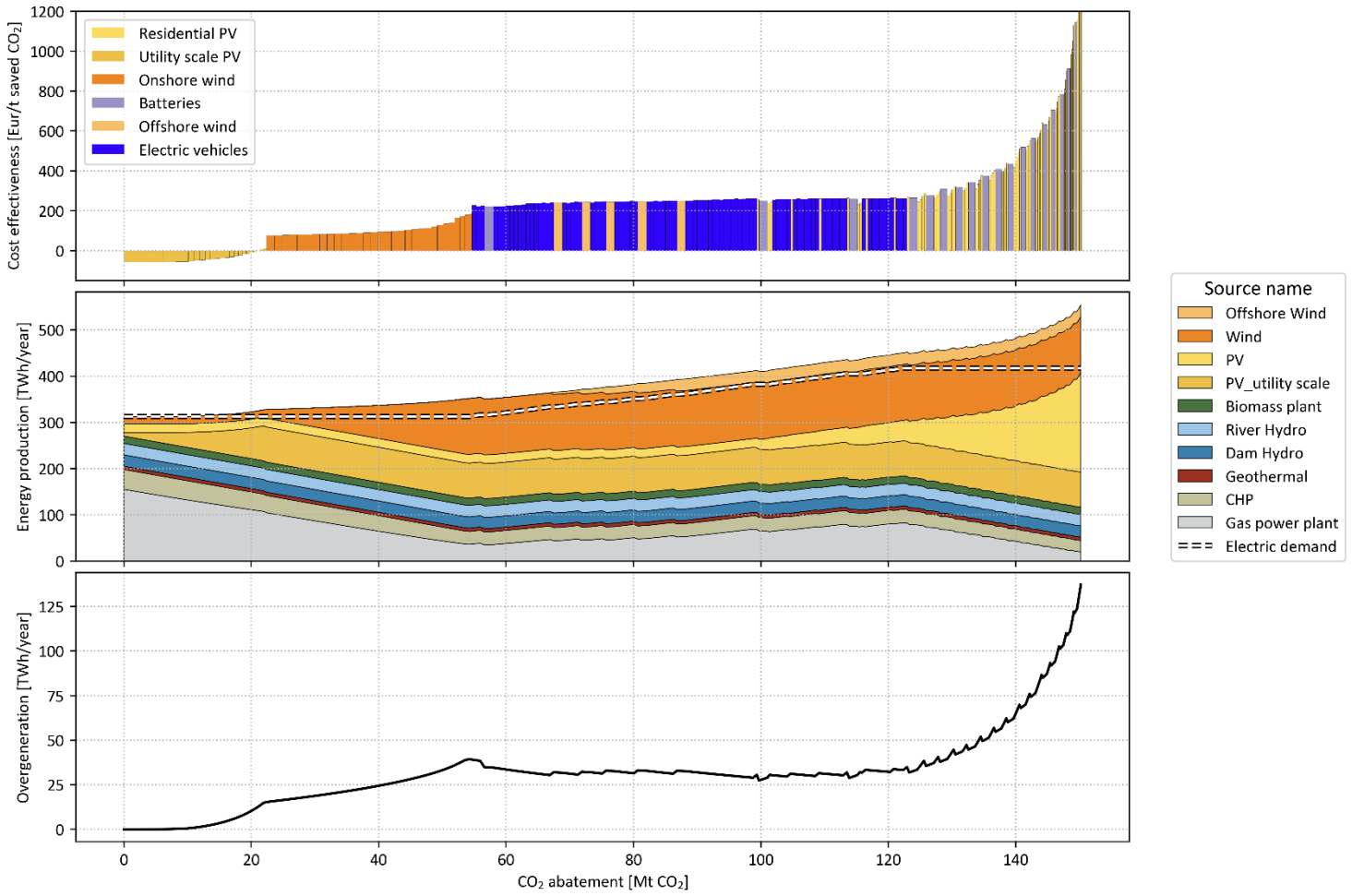
The last segment is characterised by batteries and residential PV with the overall CE which increases exponentially.

Results - Total annual costs



Fossil fuels related costs show a clear decreasing trend balanced by RES annual investment costs

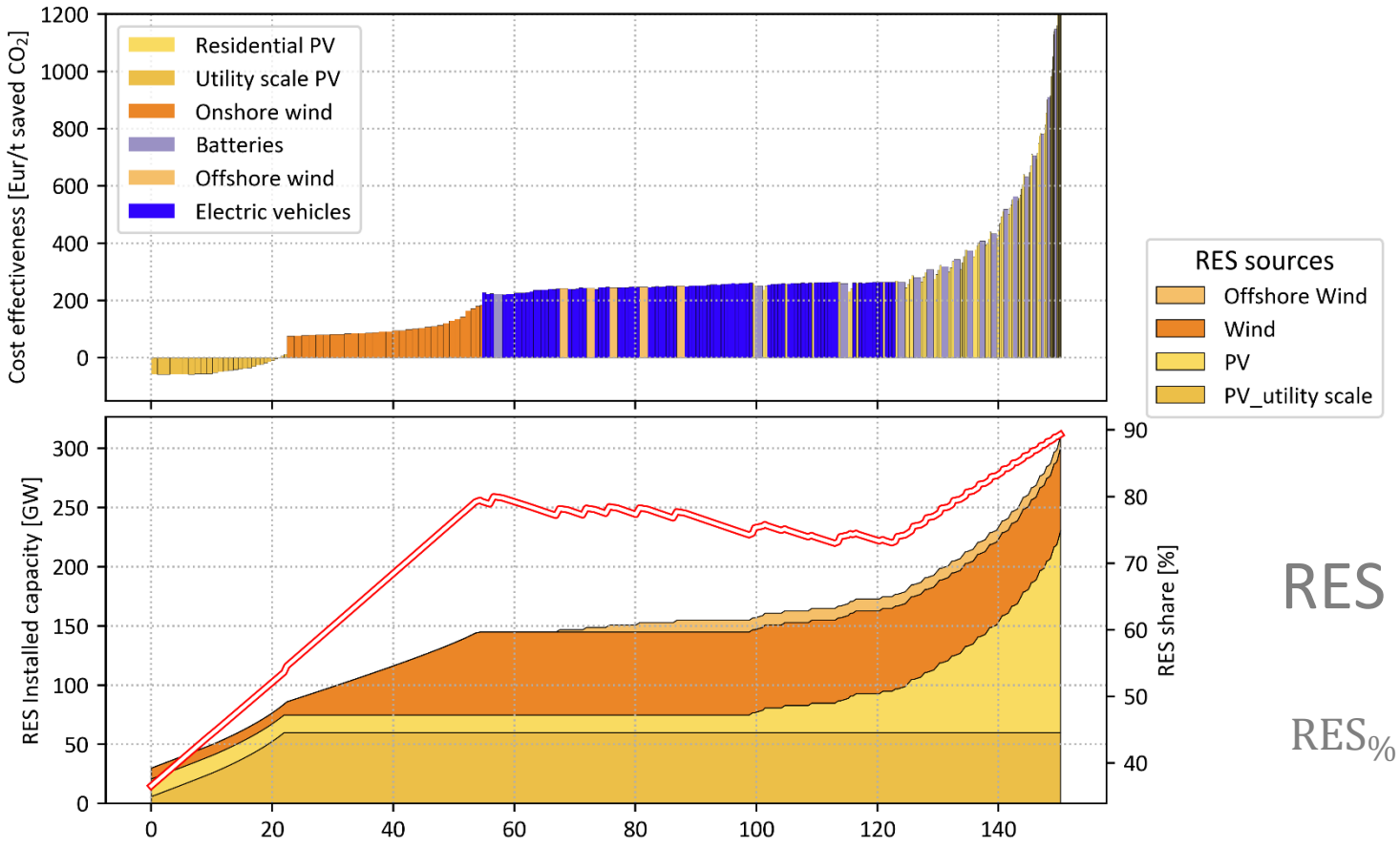
Results - Energy mix and overgeneration



The RES uptake generates a growing overproduction that must be managed with grid stabilization measures

Vehicles dump charge helps decreasing this trend together with storage installation. The overgeneration increases exponentially in the last segment of the MAC curve producing a similar trend in the CE.

Results - Installed Capacity trends



RES share defined as

$$\mathrm{RES}_{\%} = \frac{\left(\mathrm{electricity}_{demand} - \mathrm{FF}_{\mathrm{production}}\right)}{\mathrm{electricity}_{demand}}$$

Conclusions

An optimization method based on EnergyPLAN has been developed to develop Marginal Abatement Cost (MAC) curves:

- This is useful as a mean to support policy-makers by providing not only the best energy mix but also information on the most cost-effective sequential order
- This is useful for modellers to understand competing decision variables and the reasons why a certain best energy mix is reached by the expansion capacity models.
- The developed method uses EnergyPLAN software and can therefore implement sector coupling and high temporal resolution. This represents the novelty of the approached compared to existing literature
- The method is open source and the full source code can be accessed and downloaded at this repository [1]

The method presents some limitations which have to be faced in future works: i) the brute-force hill climbing method could reach and stuck into a local minimum in the optimization process, ii) the method focuses on one single year (short-term approach) and is not able to study the whole transition (long-term approach).

[1] https://github.com/matpri/EPLANoptMAC

Thank you
for your attention

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