5th International Conference on Smart Energy Systems
Copenhagen, 10-11 September 2019
#SESAAU2019

# Analysis of Smart Energy System approach in local Alpine regions - a case study in Northern Italy

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# Summary

- Introduction: Valle d'Aosta case study*
- Low-carbon future scenarios
- Results
  - Techno-economic analysis
  - Optimization analysis ($CO_2$ vs Cost)
- Conclusions
- Future developments

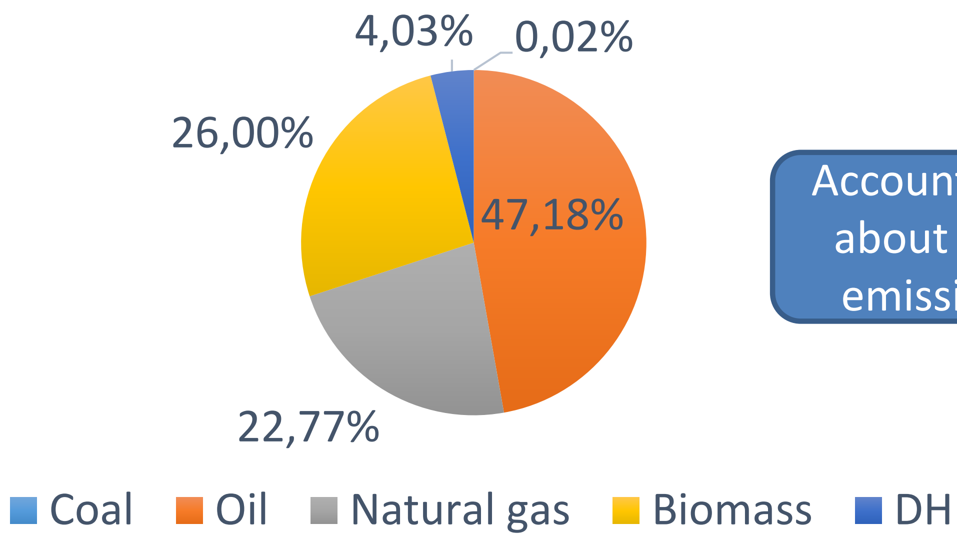
*The analysis is performed in the framework of IMEAS Project, co-financed by the European Union via Interreg Alpine Space

# Introduction: Valle d'Aosta case study

Hydro power production exceeds more than 3 times the electricity demand

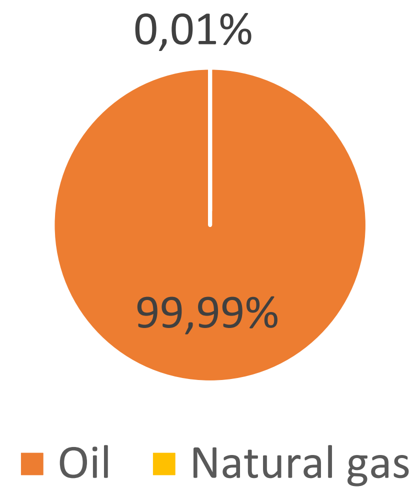
**Electrification**

**Heating for residential and services - 2015**




Account together for about 80% of total emissions in 2015

**Transport sector - 2015**



# Introduction: Valle d'Aosta case study

## Research Question:

- **Investigation of low-carbon scenarios** with the use of local resources, **optimizing the total cost** of the energy system and **$CO_2$ emissions reduction**.

## Methodology

- Techno-economic analysis using *EnergyPLAN.*
- Optimization analysis using genetic algorithm.

# Low-carbon future scenarios

## Technical assumptions

- Increase of **Heat Pumps** up to 60%, phase-out of oil boilers
- Shift from **oil to biofuels** consumption up to 50%
- Shift from **oil to natural gas** consumption up to 65%
- Exploitation of **local dung wastes to** produce **biogas**

→ HP-ref, HP-Low, HP-Mid, HP-High

- **Penetration of electric vehicles** up to 80% of light-duty fleet
- **Substitution** of **diesel heavy trucks with fuel cell ones** up to 30%

→ 0%EV, 20%EV, 50%EV, 80%EV

# Low-carbon future scenarios

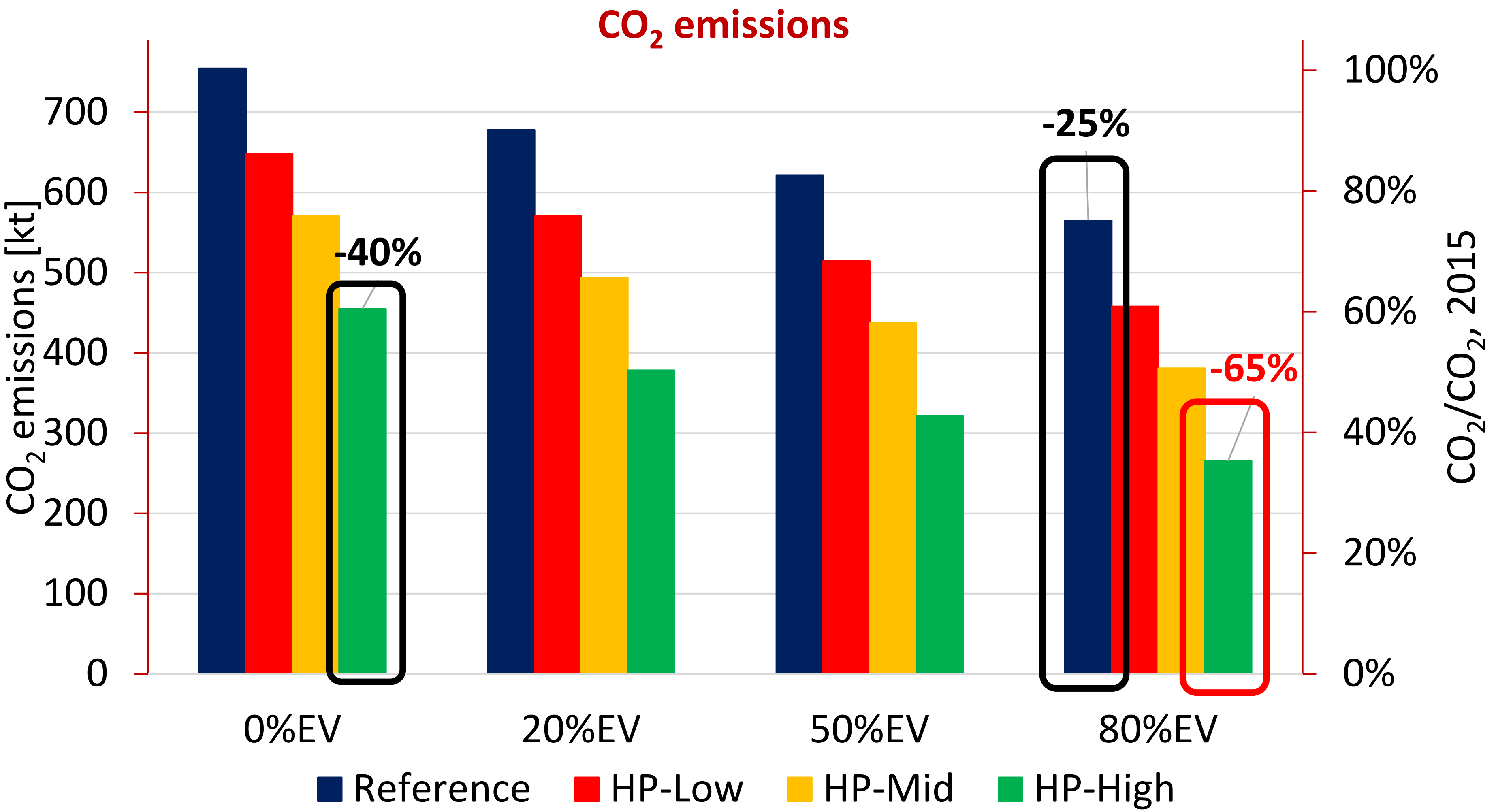
## Economic assumptions:

- **Reference year: 2050**
- Cost of **all the technologies (excl. transport)**: **Cost database**, output of **HRE4** (Heat Roadmap Europe 4) project
- **Conventional cars and electric vehicles prices** are derived from **UNRAE database**
- **Diesel trucks and $H_2$ trucks prices** are extracted from a publication* of **Climate Technology Centre and Network**

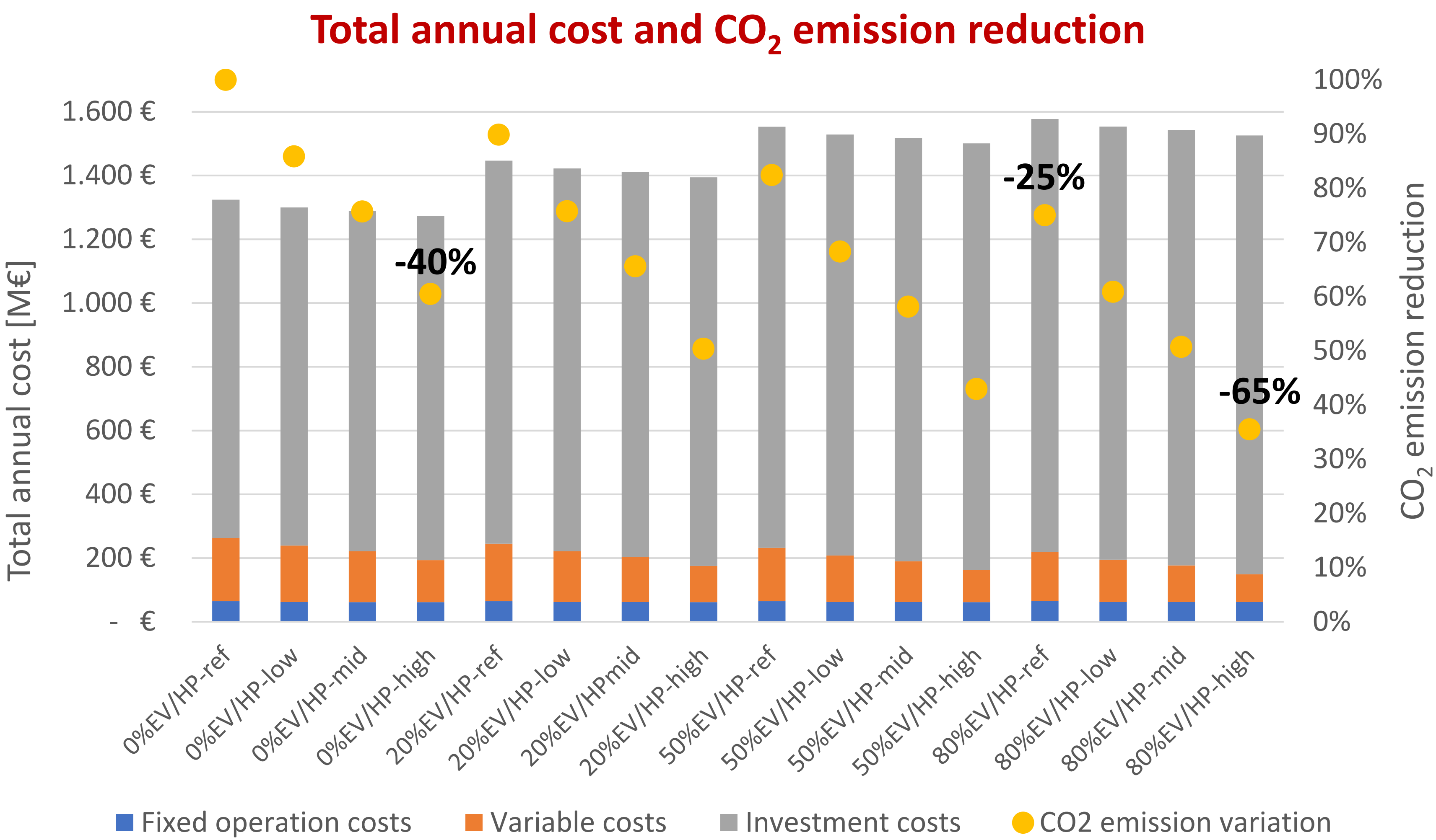
| Vehicles | Cost [k€] |
|---|---|
| **Conventional car** | 21.64 |
| **Electric vehicle** | 32.75 |
| **Diesel heavy truck** | 78.00 |
| **Fuel Cell heavy truck** | 115.00 |

*Heavy-duty trucks- Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities, https://www.ctc-n.org/resources/heavy-duty-trucks-development-business-cases-fuel-cells-and-hydrogen-applications-regions

# Results: techo-economic analysis



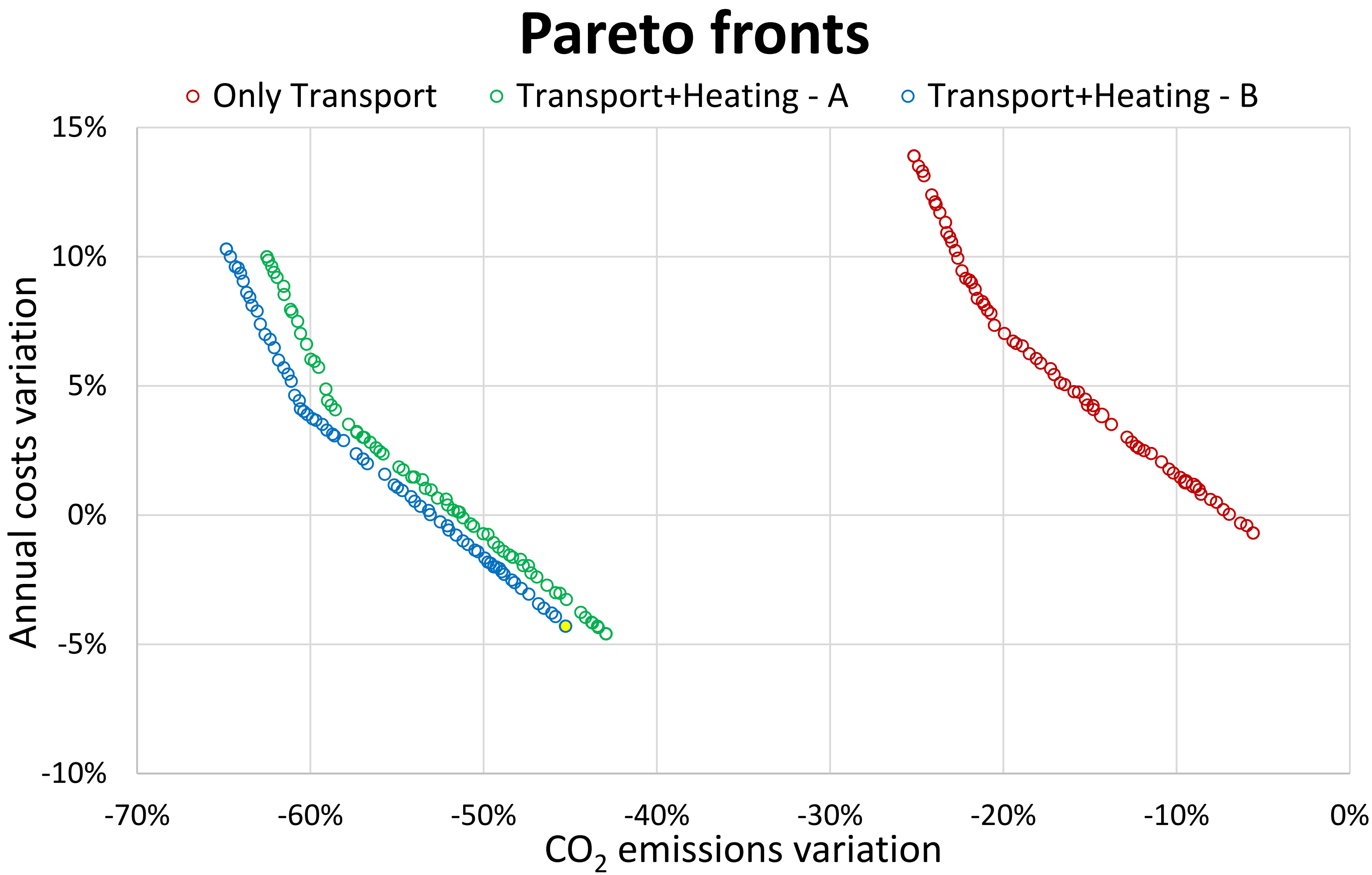
# Results: techo-economic analysis



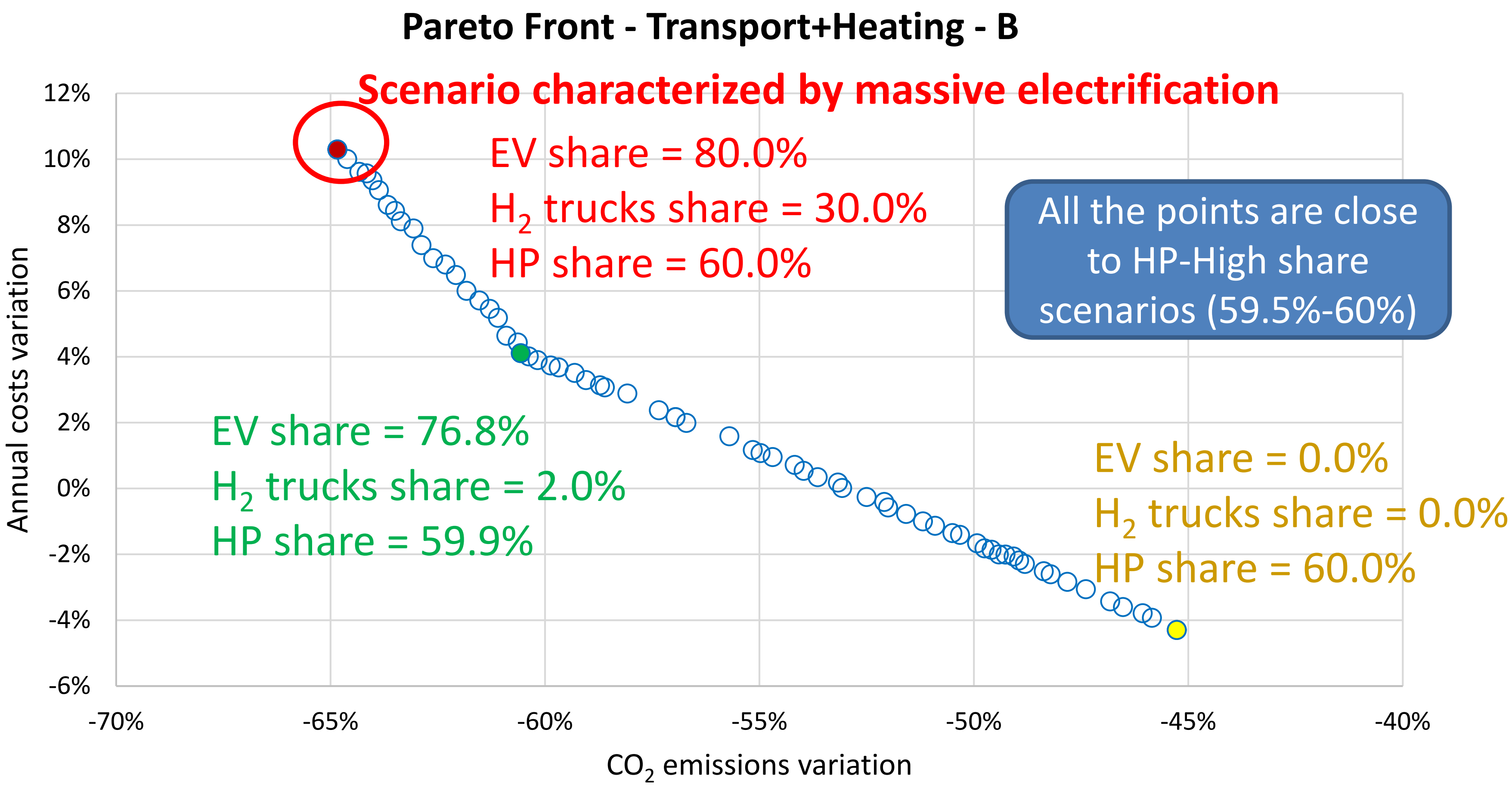
# Results: optimization analysis

- **Optimization performed** using genetic algorithm (NSGA), a **MOEA Multi-Objective Evolutionary Algorithm [MATLAB]**
- **Objective**: **minimize annual costs and $CO_2$ emissions**
- **Decision variables**:
  - petrol LDV consumption;
  - diesel LDV consumption;
  - number of diesel HDV;
  - oil boilers consumption;
  - NG boilers consumption;
  - HP heat demand.
- **Cases:**
  - Only Transport (all the other sectors as reference scenario)
  - Transport+Heating - A (industry and agriculture sectors as reference scenario)
  - Transport+Heating - B (industry and agriculture as HP-High scenario)

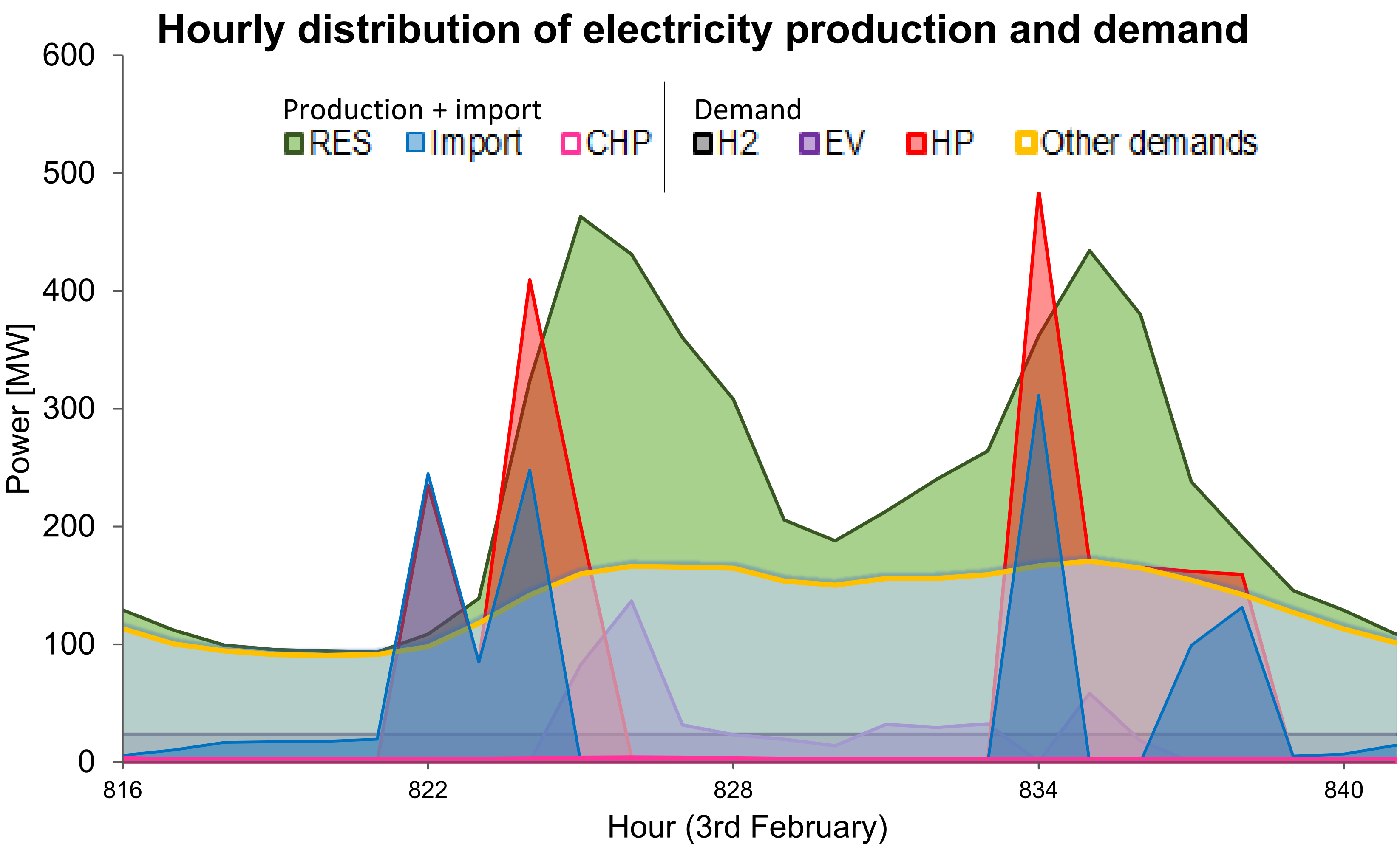
# Results: optimization analysis



# Results: optimization analysis



# Results: optimization analysis



# Conclusions

- The technical analysis illustrates:
  - **45% $CO_2$ reduction** acting on the **heating**, **industry and agriculture sectors**;
  - **25% $CO_2$ reduction** acting only on the **transport sector**;
  - **65% $CO_2$ reduction** in **HP-High/80%EV scenario**;
- **Optimized scenarios** are characterized by **high-share of heat pumps** because it does **not affect the total annual cost** and it allows to **reduce $CO_2$ emission**
- The **electricity importation in high-electrified scenarios has been identified.**

# Future developments

- Evaluation for integration of **electricity storages** in order to improve the Sector Coupling (Power-to-X) and the Smart Energy System Approach.
- Further analysis about **$CO_2$ and other emissions**
- **Optimization analysis** may be **enhanced** introducing further decision variables in other sectors.

# Thank you for your kind attention!

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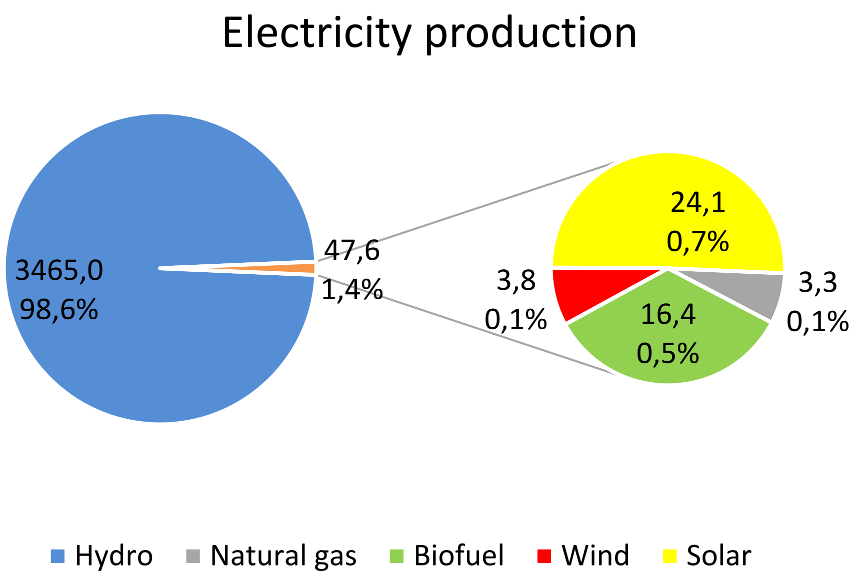
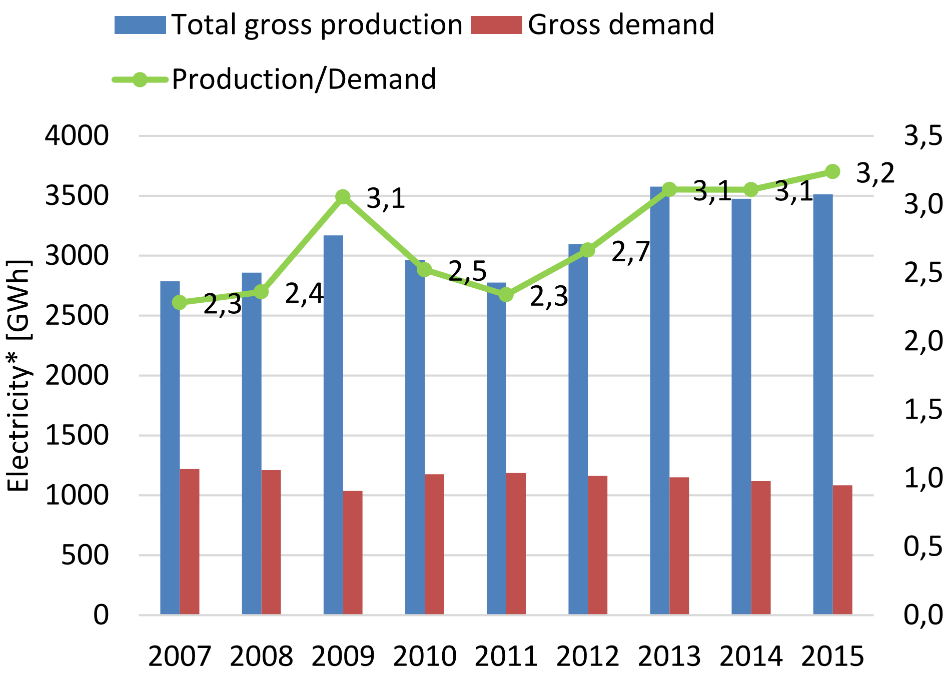
# Supporting information

- Valle d'Aosta 2015
- Low-carbon scenarios assumptions
- Surplus of RES electricity
- Annual electricity importation

# Valle d'Aosta 2015

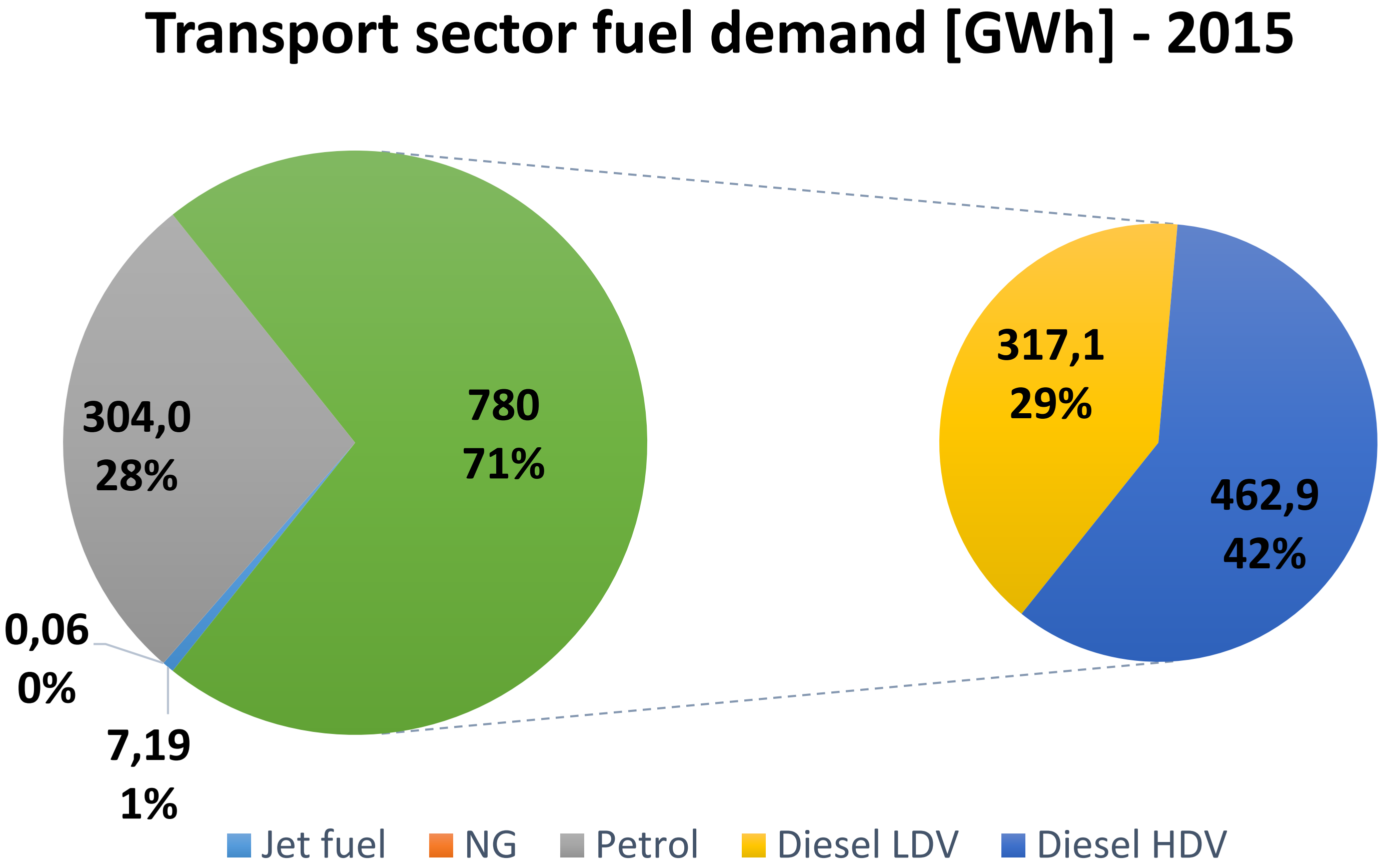



*Includes electricity production and distribution losses*

* Source: "Exploring potential synergies among energy sectors in alpine regions: the case of Valle d'Aosta" presentation in Proceedings of ECOS 2019 - The 32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental impact of Energy Systems – June 23-28, 2019 – Wroclaw, Poland

# Valle d'Aosta 2015



# Low-carbon scenarios assumptions

| Technology | Share of total heating demand | | | | Assumptions |
|---|---|---|---|---|---|
| | 2015-ref | HP-Low | HP-Mid | HP-High | |
| **Heat pump** | 2.0% | 10.0% | 30.0% | 60.0% | increase up to 60% |
| **Oil boiler** | 46.4% | 15.0% | 10.0% | 0.0% | gradual phase-out |
| **Biomass boiler** | 24.0% | 24.0% | 24.0% | 24.0% | constant |
| **District heating** | 3.9% | 8.6% | 7.8% | 6.5% | slight decrease of fossil DH |
| **Natural gas boiler** | 23.7% | 42.3% | 28.2% | 9.5% | remaining part |

Other assumptions:

- Energy efficiency in buildings: **heat demand -10%;**
- Heat pumps **COP +25%** from 2.5 to 3.1;
- **DH demand** initially grow (LOW scenario) due to a **new CHP plant** in the area of Cervinia that is currently in exercise

# Low-carbon scenarios assumptions

| Sector | Fuel | Fuel consumption [GWh] | | | | Assumptions |
|---|---|---|---|---|---|---|
| | | 2015-ref | HP-Low | HP-Mid | HP-High | |
| **Industry** | **Oil** | 145.9 | 114.3 | 82.7 | 51.1 | Reduction up to 65% |
| **Industry** | **Natural Gas** | 423.7 | 455.3 | 486.9 | 518.5 | Shift from oil |
| **Industry** | **Biomass** | 13.9 | 13.9 | 13.9 | 13.9 | Constant |
| **Agriculture** | **Oil** | 19.9 | 16.6 | 13.3 | 10.0 | Reduction up to 50% |
| **Agriculture** | **Biofuel** | 0.1 | 3.4 | 6.8 | 10.1 | Shift from oil |

Other assumptions:

- **Biogas production**, exploiting dung waste and other farming wastes, **increases** gradually until 46.76 GWh/year in the high scenario (upgraded to methane – to the grid)

# Low-carbon scenarios assumptions

| Vehicle type | Share of total Light duty fleet | | | | Electricity and fuel consumption [GWh] | | | |
|---|---|---|---|---|---|---|---|---|
| | 0%EV | 20%EV | 50%EV | 80%EV | 0%EV | 20%EV | 50%EV | 80%EV |
| **Electric LDV** | 0% | 20% | 50% | 80% | 0.0 | 36.5 | 91.1 | 145.8 |
| **Petrol LDV** | 50% | 65% | 40% | 15% | 304.0 | 387.6 | 238.8 | 90.2 |
| **Diesel LDV** | 50% | 15% | 10% | 5% | 317.1 | 79.7 | 53.1 | 26.6 |

| Vehicle type | Share of total Heavy duty fleet | | | | Fuel consumption [GWh] | | | |
|---|---|---|---|---|---|---|---|---|
| | 0%EV | 20%EV | 50%EV | 80%EV | 0%EV | 20%EV | 50%EV | 80%EV |
| **Diesel HDV** | 100% | 90% | 80% | 70% | 462.9 | 328.6 | 292.1 | 255.6 |
| **H2 HDV** | 0% | 10% | 20% | 30% | 0.0 | 35.2 | 70.5 | 105.7 |

# Low-carbon scenarios assumptions

| Transport vehicle consumption [kWh/100km] | | | | |
|---|---|---|---|---|
| Vehicles | Scenarios | | | |
| | 0%EV | 20%EV | 50%EV | 80%EV |
| **Diesel heavy trucks[1]** | 251.0 | 198.0 | 198.0 | 198.0 |
| **Fuel cell heavy trucks[1]** | 211.0 | 191.0 | 191.0 | 191.0 |
| **Petrol cars[2]** | 57.5 | 51.3 | 51.3 | 51.3 |
| **Diesel cars[2]** | 50.0 | 45.7 | 45.7 | 45.7 |
| **Electric Vehicles[3]** | 18.4 | 15.7 | 15.7 | 15.7 |

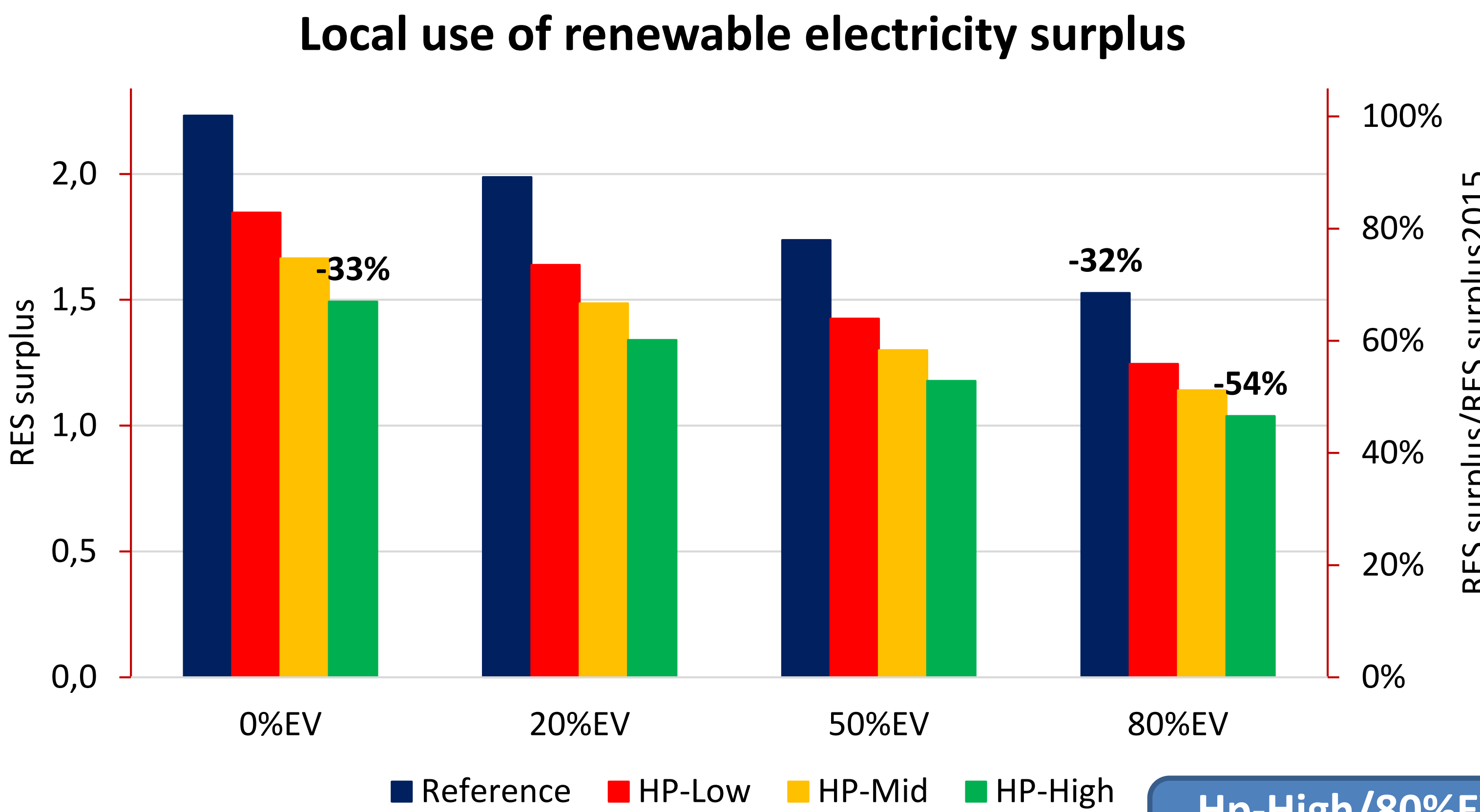
[1] Climate Centre and Network, Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities.
[2] Fuel economy for conventional cars derived from Unione Petrolifera current and projected estimations.
[3] EV technical specifications derived from a weighted average from the actual national fleet composition.

# Low-carbon scenarios assumptions

**Low-carbon scenarios: 16 combinations**

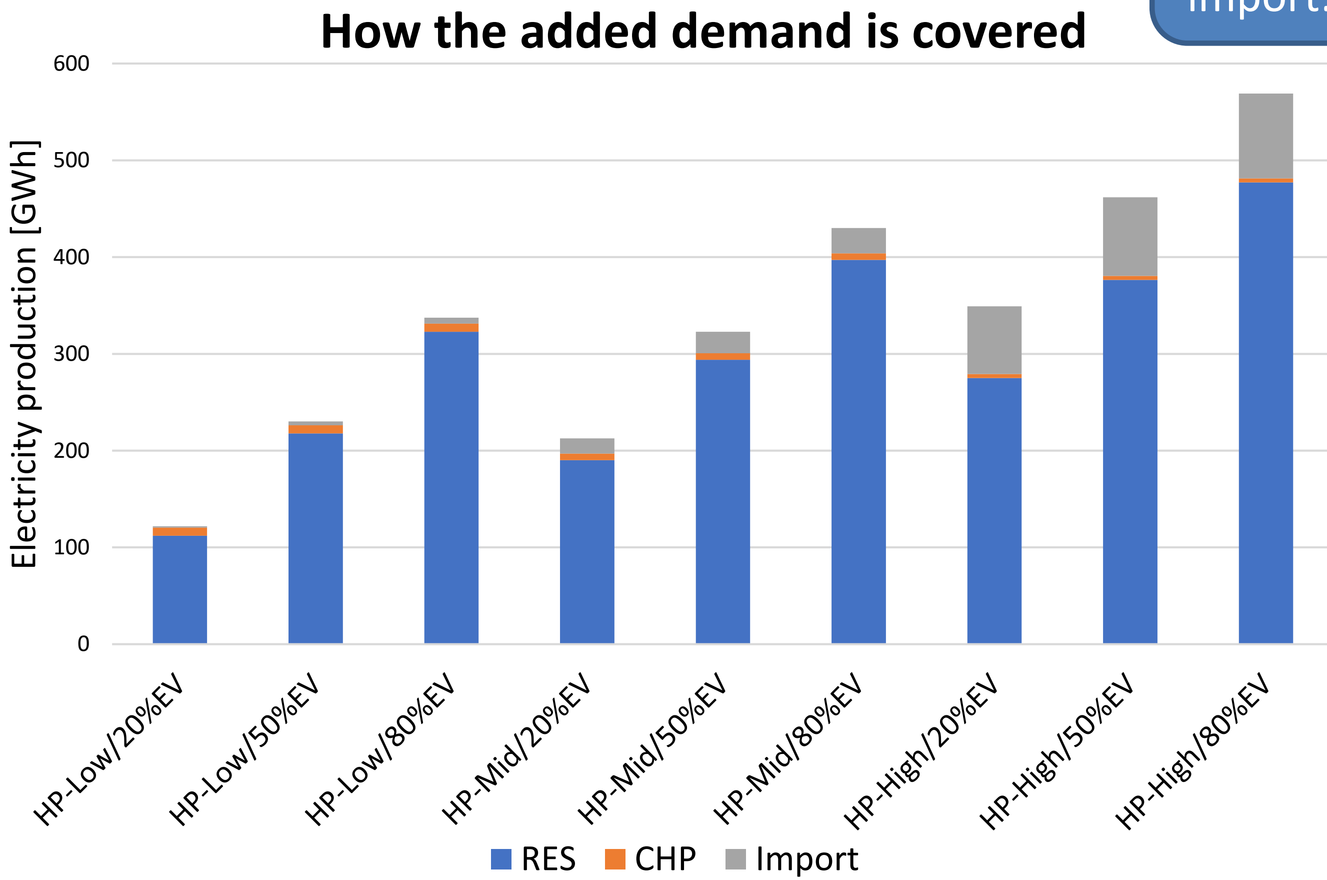
| | **0%EV** | **20%EV** | **50%EV** | **80%EV** |
|---|---|---|---|---|
| **HP-ref** | HP-ref/0%EV | 2015-ref/20%EV | 2015-ref/50%EV | 2015-ref/80%EV |
| **HP-Low** | HP-Low/0%EV | HP-Low/20%EV | HP-Low/50%EV | HP-Low/80%EV |
| **HP-Mid** | HP-Mid/0%EV | HP-Mid/20%EV | HP-Mid/50%EV | HP-Mid/80%EV |
| **HP-High** | HP-High/0%EV | HP-High/20%EV | HP-High/50%EV | HP-High/80%EV |

# RES surplus




**Hp-High/80%EV**
Export=1624 GWh

# Annual importation




**HP-High/80%EV**
Electricity import: 86 GWh