IDS.S31: Decision Support Models for Low-Carbon Electric Power Systems

Impact of Renewables on System Operation in Practice

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Motivation

- Evaluation of the impact of renewables at different time scales on the system operation

- See some applications of complex models

Contents

1. ROM Operation Model

2. ROM Case studies

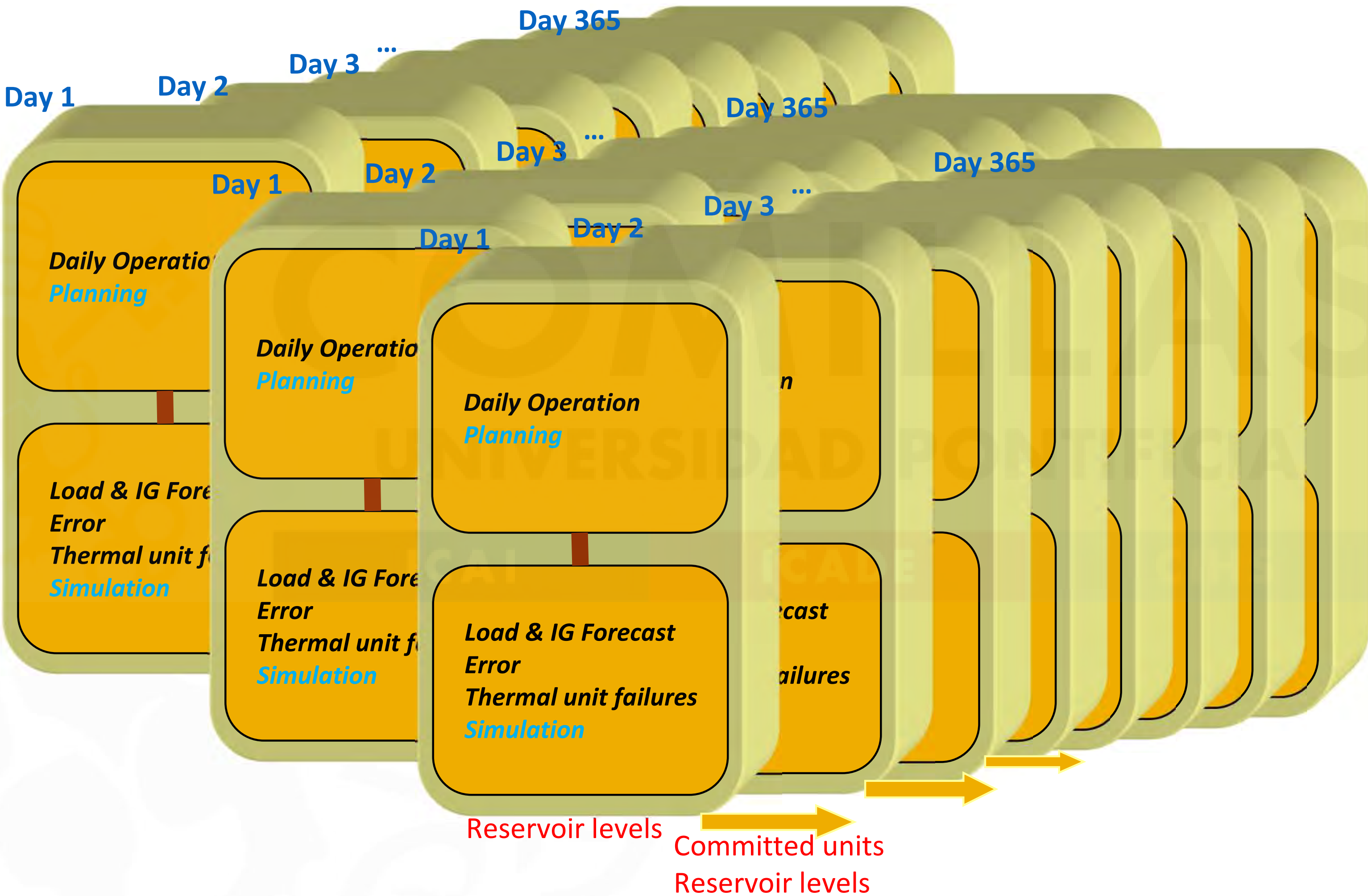
1

ROM Operation Model

ROM (Reliability and Operation Model for Renewable Energy Sources) (https://pascua.iit.comillas.edu/aramos/ROM.htm)

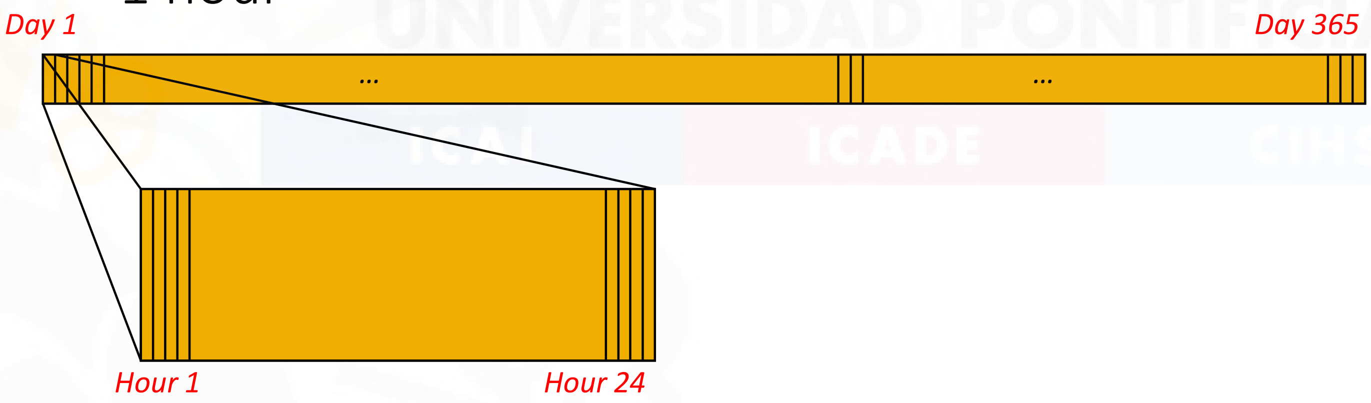
- Determine the technical and economic impact of intermittent generation (IG) and other types of emerging technologies (active DR, EVs, CSP, CAES) into the medium-term system operation including reliability assessment.
- The model paradigm based on a daily sequence of planning and simulation is similar to an open-loop feedback control used in control theory.

General overview



Time division

- Scope
  - 1 year
- Period
  - 1 day (consecutive chronological operation)
- Subperiod
  - 1 hour



Model overview. Yearly simulation

- Stochasticity taken into account by yearly scenarios obtained by Monte Carlo simulation
  - Relevant uncertainty: demand, wind/solar generation, hydro inflows
  - Random variables considered independent
    - Rare events (such as several low wind days) may involve a large number of scenarios (variance reduction techniques may be needed)

Model overview. Seasonal operation

- Decisions above daily scope as the weekly scheduling of storage hydro and pumped storage hydro plants are done internally in the model by heuristic criteria.
- Hydro scheduling given by a high level hydrothermal coordination model
- Pumped storage hydro scheduling:
  - Weekly pumped hydro scheduling

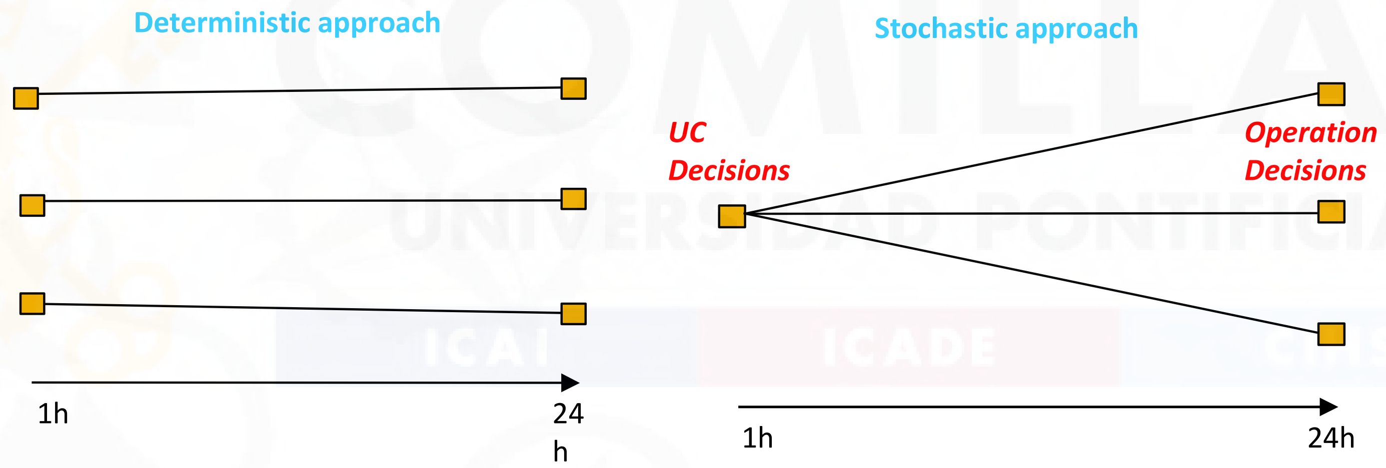
La Muela de Cortes

Model overview. Daily DETERMINISTIC operation planning

- Daily operation model repeated 365 days
- This system modeling in two phases reproduces the usual decision mechanism of the system operator.
  - First, deterministic optimization of operation decisions
    - Daily network constrained unit commitment and economic dispatch
  - Then, simulation of unknown events
    - Load forecast errors
    - Hourly simulation of unit failures
    - Adapt and correct previous decisions to real IG (forecast error)
    - Deployment of corrective actions used in a predefined sequence (increase hydro production, use operating reserve, demand response, EV, etc.)
- Connection between consecutive days
  - Commitment status of thermal units
  - Hydro reservoir levels
  - Other state variables

Model overview. Daily STOCHASTIC operation planning

- Different wind prediction errors considered:
  - 1st stage decision: **Daily Unit Commitment** of inflexible units
  - 2nd stage decision: **Economic dispatch**, Unit Output, Energy Not Served



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Daily operation planning

- Objective function: cost minimization
  - Thermal variable costs:
    - Fuel Cost
    - O&M Cost
    - CO_2 Cost
    - Startup costs
  - Unscheduled hydro variable costs
  - Penalty by deficit of up or down operating reserve
  - Cost of Energy Not Served

Daily operation planning

- Constraints (I)
  - System:
    - Generation-load hourly balance at every node
    - Up and down hourly operating reserve
    - Second Kirchhoff's circuit law (DC load flow)
    - Maximum flow through the lines of the network
    - Ohmic losses modeled with a piecewise linear approximation or proportional to the flow
  - Thermal units:
    - Startup, shutdown and commitment of thermal units
    - Bound on thermal power operating reserve + thermal power output (minimum load)
    - Up and down thermal unit ramps
    - Exponential thermal startup costs
    - Minimum up-time and down-time of thermal units

Daily operation planning

- Constraints (II)
  - Hydro and pumped hydro units:
    - Bound on pumped storage hydro up and down operating reserve
    - Water inventory in hydro storage reservoirs and pumped storage hydro reservoirs
    - Bound on hydro power output
    - Daily hydro output target
  - Electric Vehicles (EV):
    - Charge and discharge
    - Inventory of state of charge (SOC) of the battery
  - Concentrated Solar Power (CSP) with storage capability
  - Generic Virtual Power Plant (VPP)
  - Price-Based Demand Response (DR)

Daily operation planning

- Positive variables
  - Flow through the lines of the network
  - Voltage angle of each node of the network
  - Up or down operating reserve of thermal unit and thermal unit output
  - Storage hydro and pumped storage hydro unit output
  - Unscheduled hydro output
  - Hydro spillage or IG surplus (curtailment)
  - Up or down operating reserve of pumped storage hydro unit
  - Up or down operating reserve of EV
  - Deficit of operating reserve
  - Energy Not Served
  - Pumped storage hydro energy target

- Binary variables
  - Commitment, startup and shutdown of thermal units
  - Indicator of pumping or turbining of pumped storage hydro units
  - Indicator of up or down operating reserve of pumped storage hydro units

Demand and reserve

- Balancing operating reserves depend on each scenario and hour
  - Up:
    - % of peak load + intermittent generation forecast error + largest thermal unit
  - Down:
    - % of peak load
- Use of demand response actions
  - Demand as a function of the price. Demand elasticity
  - Demand shifting
  - Peak clipping

Thermal units

- Minimum and maximum output
- Up and down ramp rates

- Planned outage rate (maintenance distributed randomly)
- Forced outage rate

- Fixed and variable heat rates and fuel price
- Emission rate and CO_2 price
- Operation and maintenance costs
- (Exponential) Start-up costs

Network

- Transmission modeled with a linearized power flow with or without ohmic losses

$$\frac{F_{ij}}{S_{base}} = \frac{1}{X_{ij}} \cdot (\theta_i - \theta_j)$$

i, j	Nodes
F_{ij}	Flow through the line $i - j$
S_{base}	Base power of the system
X_{ij}	Reactance of the line $i - j$
θ_i	Voltage angle of node i

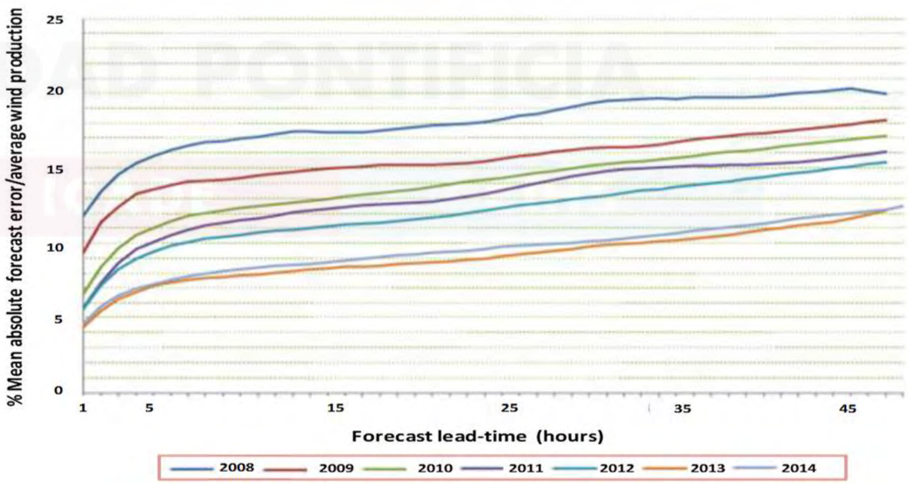
- Ohmic losses modeled with a piecewise linear approximation
- Representative distribution network with quadratic losses

Wind generation

- Output forecast at midday for every day to be used by the day-ahead unit commitment
  - It is subtracted from demand
- Forecast errors of previous forecast to be used in the simulation process:
  - 5 hours in advance:

    10% error
  - 24 hours in advance:

    15% error



Source: REE

EV data

- Mobility patterns
  - Daily distance
  - SOC at the beginning of the day
  - Usage for every hour
  - Connection percentage for every hour
- EV fleets (type of uses)
  - Number of EV
  - Mobility patterns used
- Battery characteristics
  - Maximum and minimum SOC
  - Efficiencies (GTB, BTW, BTG)
  - Maximum charging and discharging rates
  - Maximum power output

Mitsubishi **i**
Miev EV

EV modeling characteristics. Smart charge/discharge decided by the model

- Provide energy services (allow charge and discharge (V2G) activities)
- Battery energy inventory
  - SOC at an hour + charge – discharge – transportation use = SOC at next hour
- Provision of battery energy for operating reserve
  - The (up and down) operating reserve offered implies to keep some energy at the battery
- Use incompatibility
  - At any hour EV must be charging or discharging
- Maximum charge bounded by the remaining battery energy times the percentage of connected EV
- Bounds on the up and down operating reserve

Local storage based on lithium-ion batteries

- 80 MWh of State of Charge

Model overview. Daily simulation. Real-time operation

- Daily operation model repeated 365 days
- This system modeling in two phases reproduces the usual decision mechanism of the system operator.
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  - Then, simulation of unknown events
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Daily simulation. Real-time operation

- Deployment of corrective actions
  - Commitment or decommitment of thermal units by increasing variable costs at minimum load at 24 h taking into consideration the IG forecast error corresponding to 24 h
  - Suppress energy not served if IG error goes in the correct direction
  - Use of storage hydro operating reserve
  - Use of pumped storage hydro operating reserve
  - Use of thermal unit operating reserve
  - Commitment of quick-start thermal units in real time

Basic results

- Operation
  - Output of different technologies (thermal, hydro, pumped hydro)
  - Fuel consumption
  - Primary energy (wind or hydro) surplus
- Emissions
  - Carbon, NOx emissions
- System reliability (adequacy measures)
  - EENS (Expected Energy Not Served)
  - LOLP (Loss of Load Probability)
  - LOLE (Loss of Load Expectation)
  - XLOL (eXpected Loss Of Load)
- System Marginal Costs

1. ROM Operation Model
2. **ROM Case studies**

2

ROM Case studies

Case studies

- TWENTIES. Transmission system operation with large penetration of Wind and other renewable Electricity sources in Networks by means of innovative Tools and Integrated Energy Solutions. Economic impact analysis of the demonstrations in task-forces TF1 and TF3. Deliverable D15.1
- SUSPLAN. Planning for Sustainability.
- MERGE. Mobile Energy Resources in Grids of Electricity Assessing Impacts from EV Presence. Deliverable D3.2
- CENIT-VERDE. Consorcio Estratégico Nacional en Investigación Técnica. Vehículo Eléctrico. Respuesta a la Dependencia Energética. Vehículo Ecológico. Realidad para la Disminución de Emisiones. Vehículo Español. Receta para la Dinamización del Empleo.
- Grid Integration of Compressed Air Energy Storage systems (CAES)
- Beyond2020. Design and impact of a harmonised policy for renewable electricity in Europe
- Market4RES. Post 2020 framework in a liberalised electricity market with large share of Renewable Energy Sources
- Distributed energy systems modeling analysis in the MIT Utility Of the Future study

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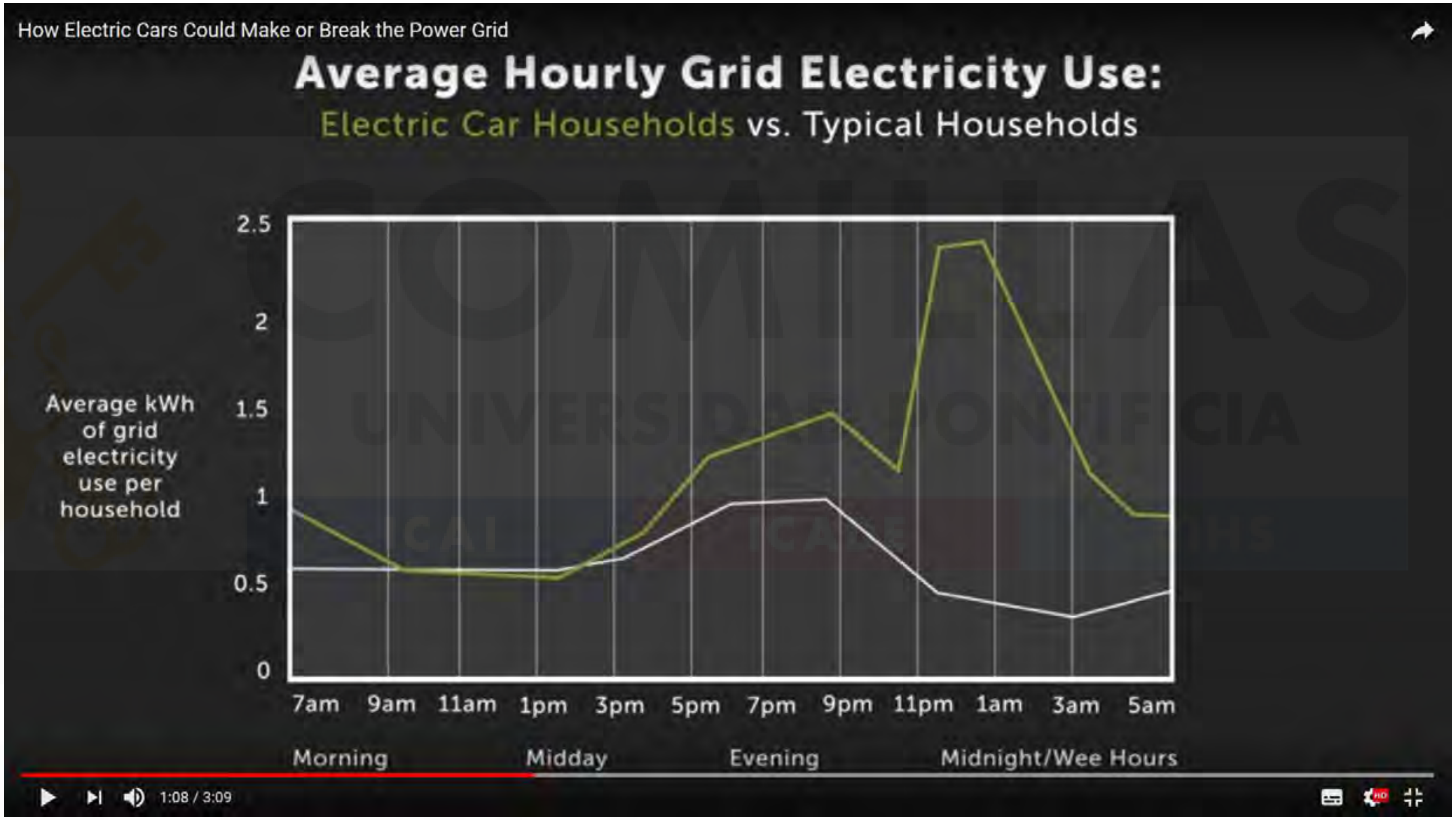
How Electric Cars Could Make or Break the Power Grid



https://www.youtube.com/watch?v=KEWzy7kHarM

Objectives

- Analyze the impact of massive integration of RES and EV in the medium and long-term operation of an electric system
- Identify and evaluate possible operation actions or regulatory measures to allow increasing the amount of RES without compromising the security of supply
- Estimate the maximum amount of IG incorporated into the system for a certain adequacy criterion (LOLP, LOLE, ENS)
- Analyze the impact of EV in the operation of the system and additional integration of WP

Systems modeled with ROM

- ➢ Mainland Spain
- ➢ Portugal

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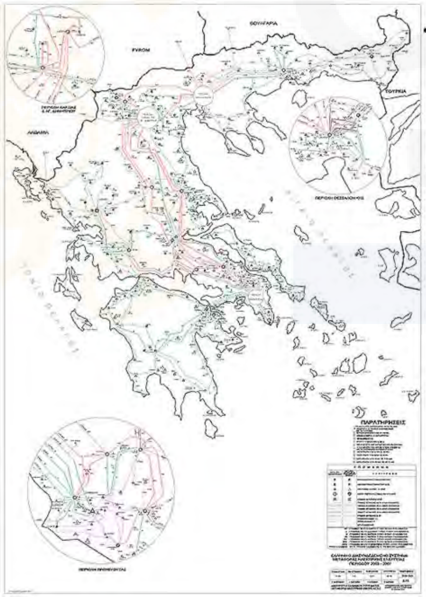
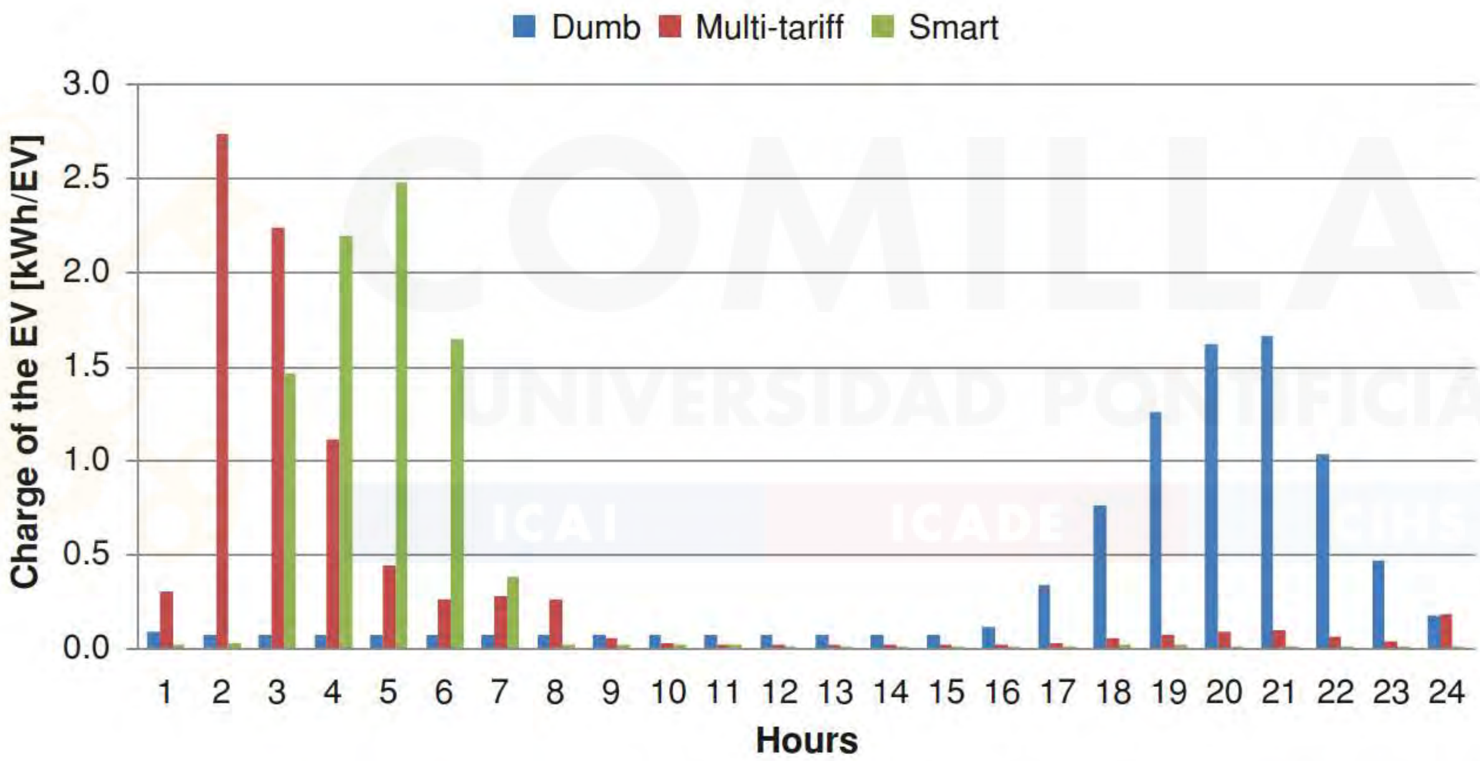


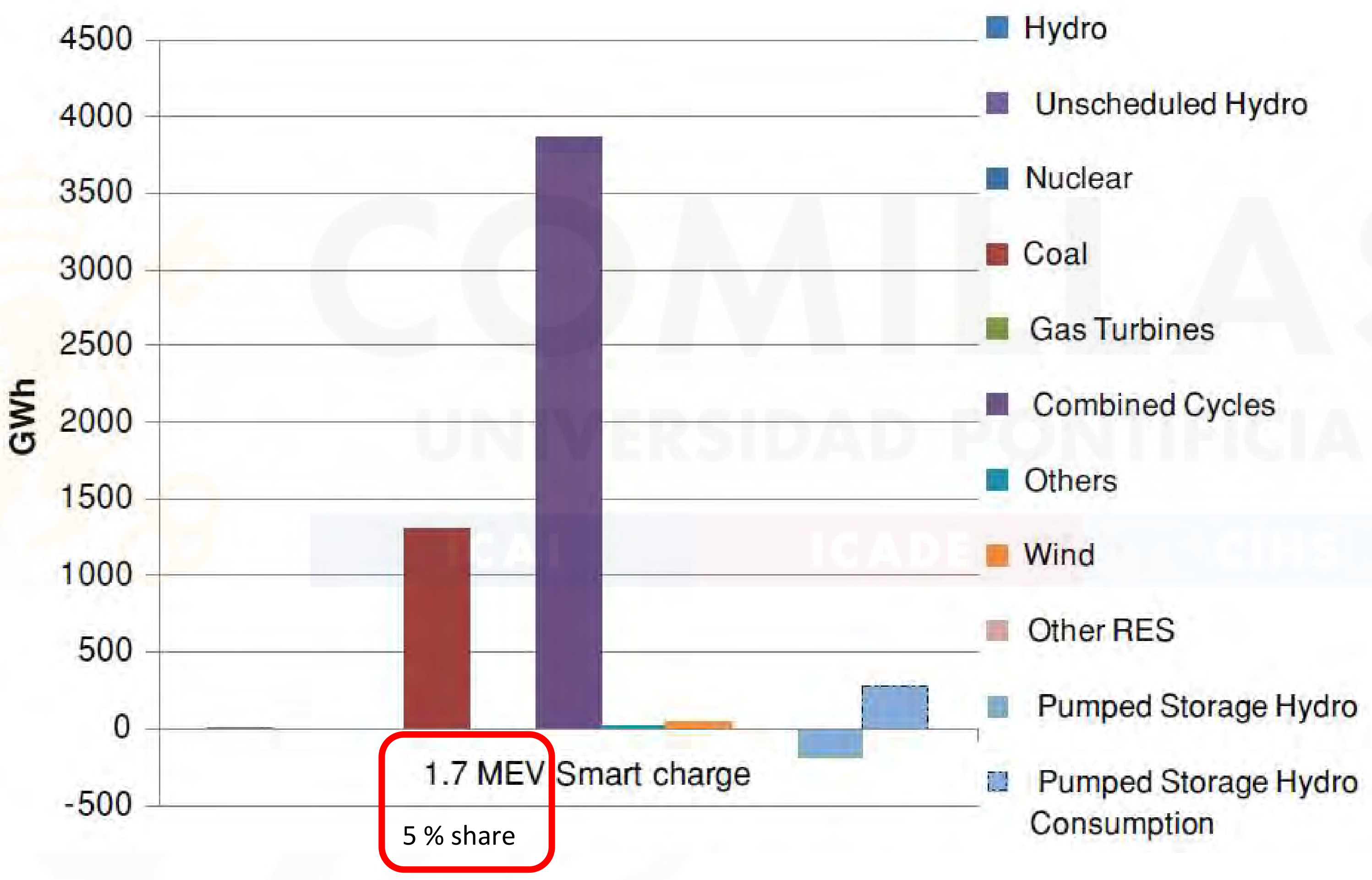
- Greece

- ➢ Canary Islands (with the electric network)

EV Charging Strategies

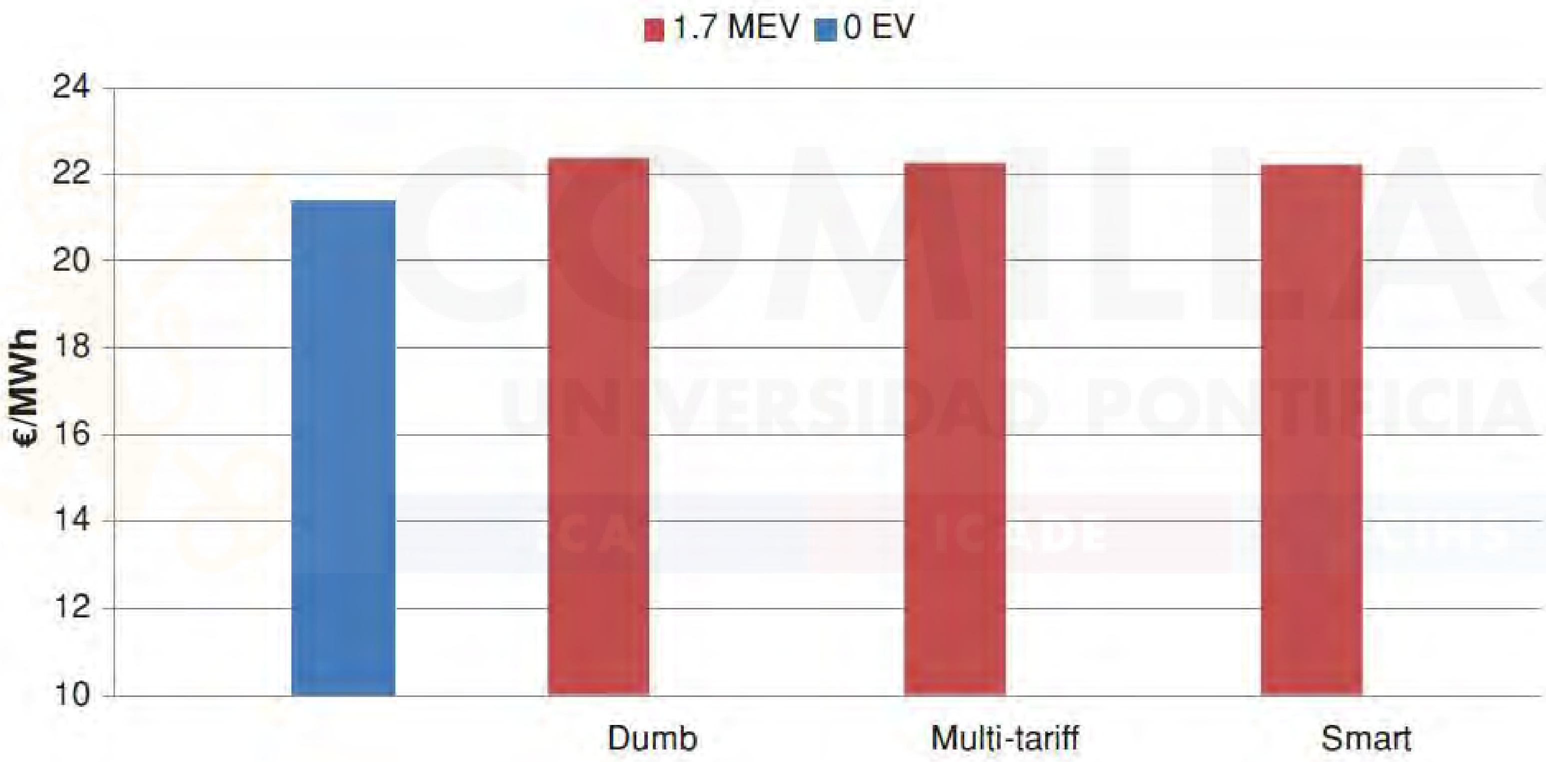


Impact of smartly charged EVs on energy produced by different technologies



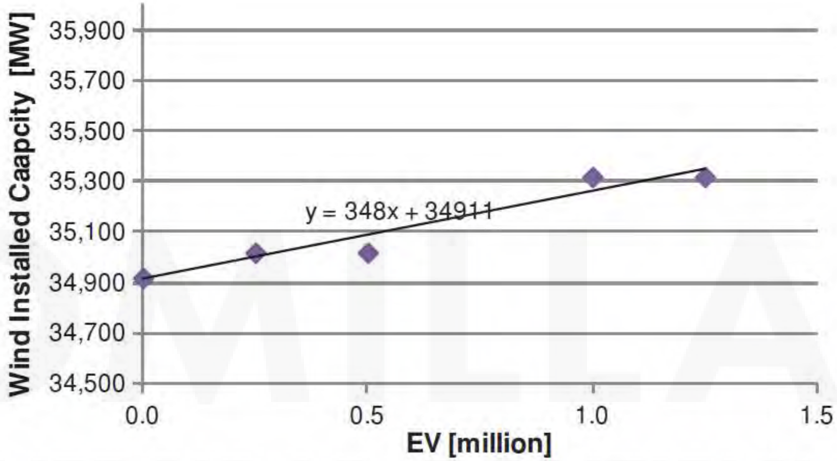
Impact on energy production by technology of the dumb and multi-tariff charging strategies with respect to values for the smart charge one, for 1.7 million EVs

Average cost of electric energy produced for each charging profile

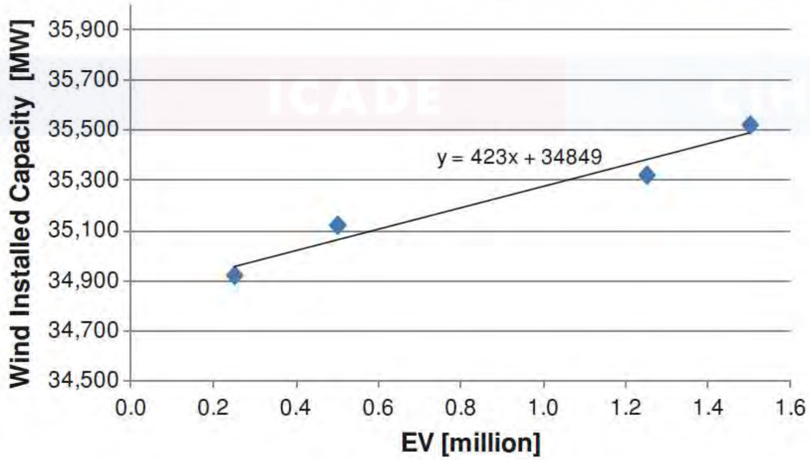


Trade-off between EV and WP

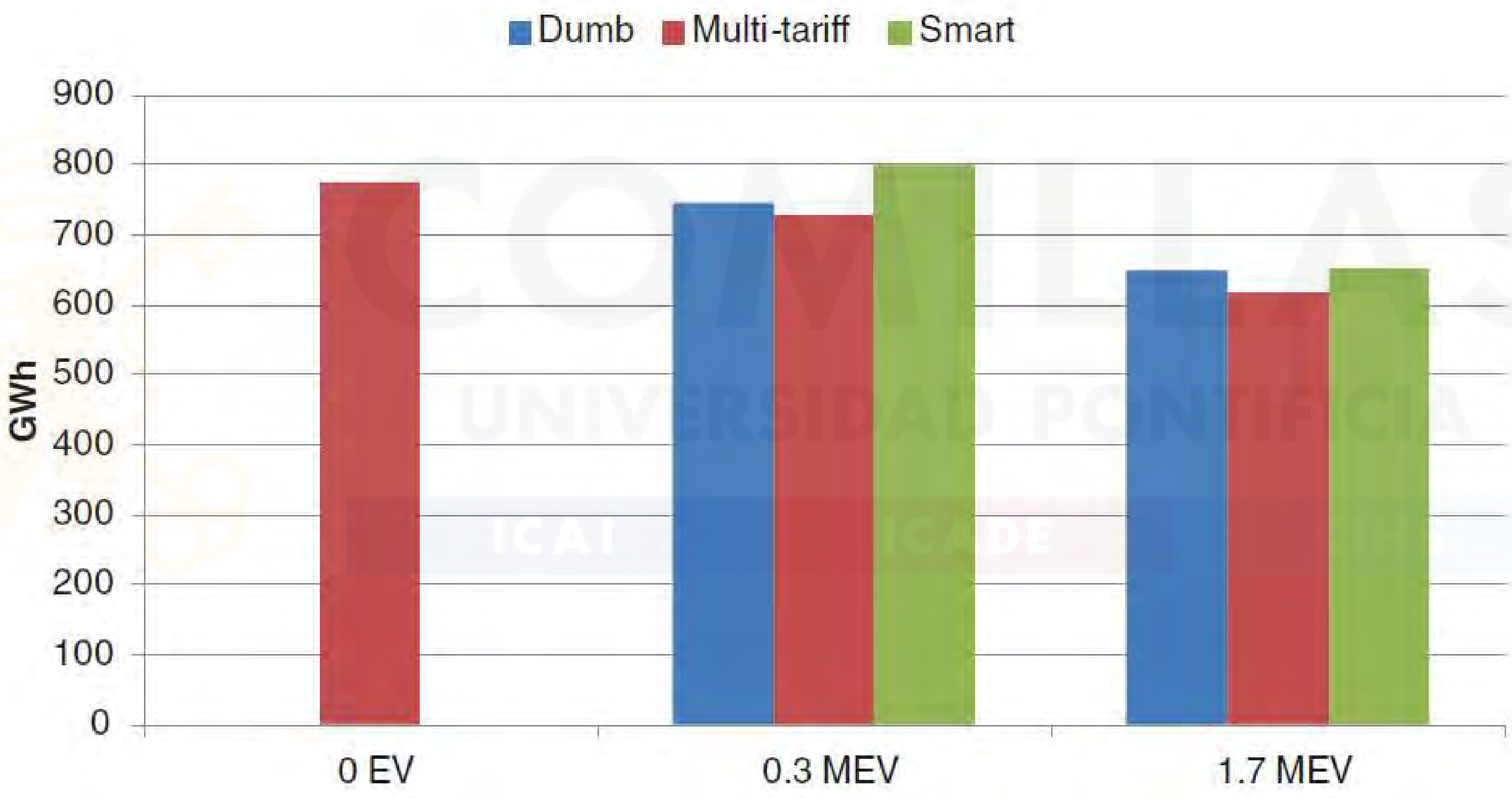
- Keeping constant EENS



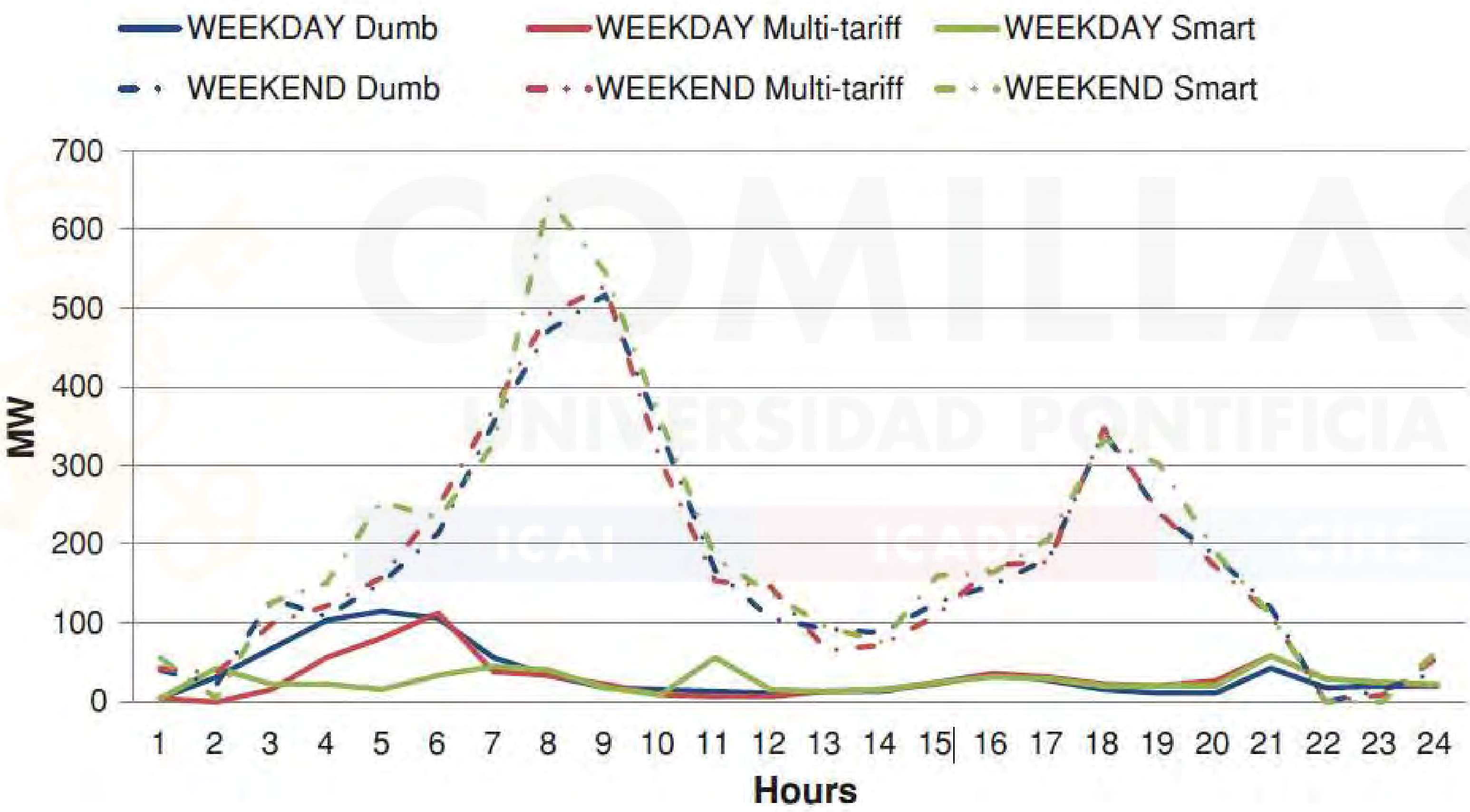
- Keeping constant operation cost



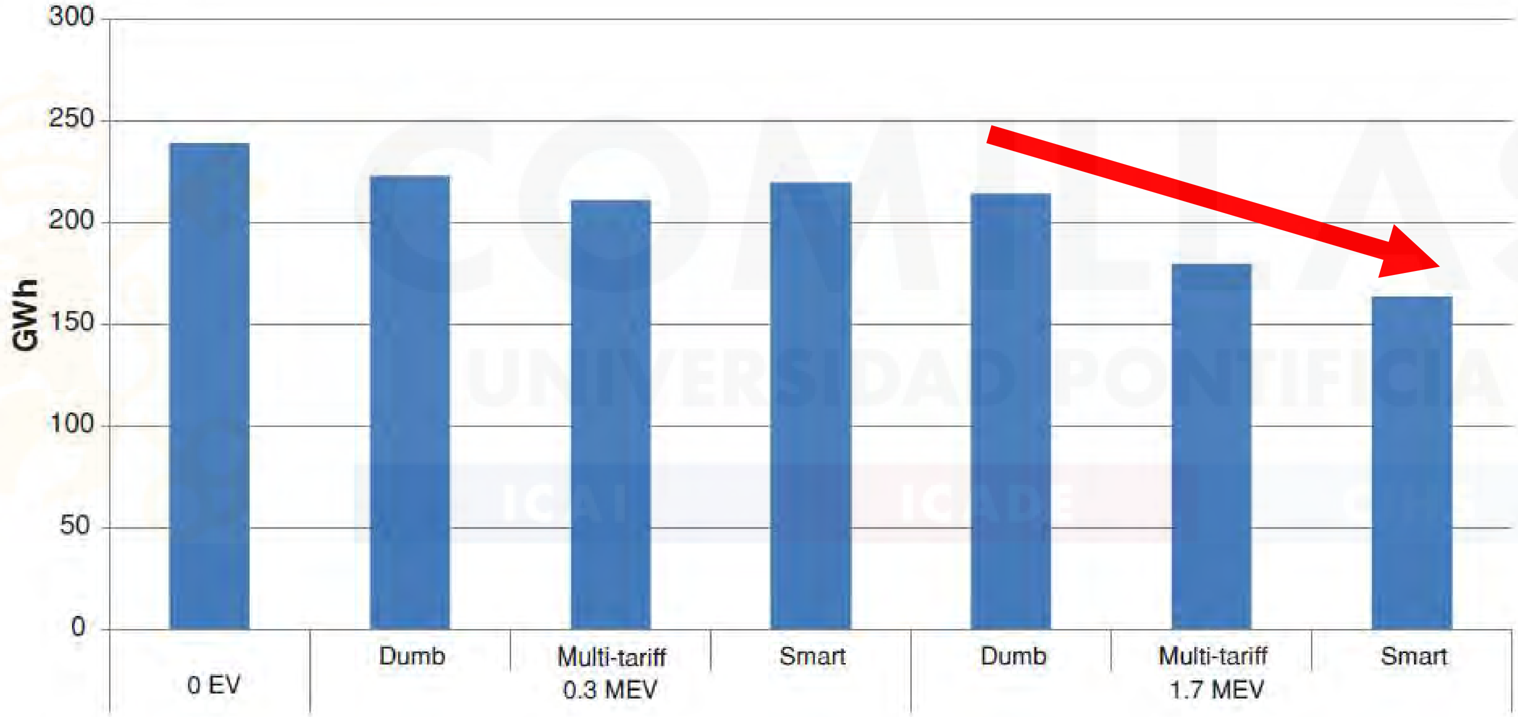
Annual RES curtailment for different number of EVs and different strategies



Profile of RES curtailment for weekends and weekdays, and the three charging strategies, in the base case

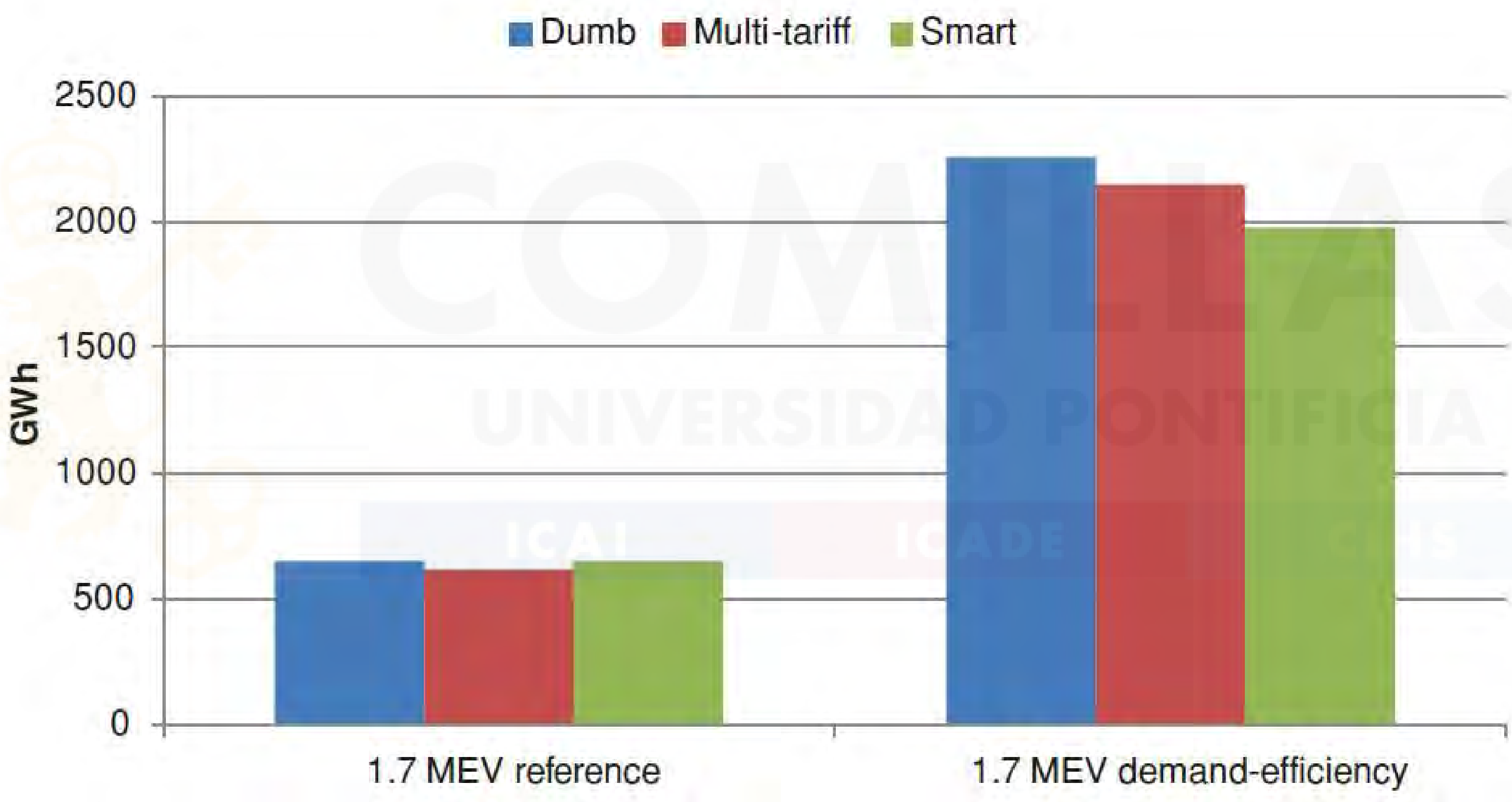


RES curtailment on weekdays for the three charging strategies

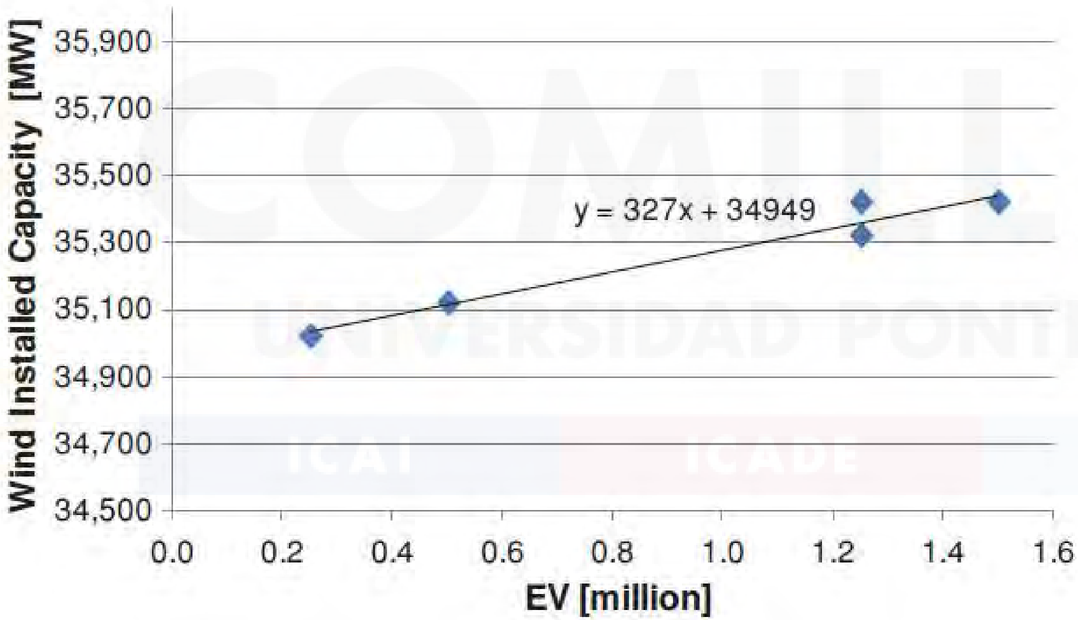


RES curtailment for the reference case and the demand-efficiency case

Demand-efficiency case decreases by 6.5 % the demand

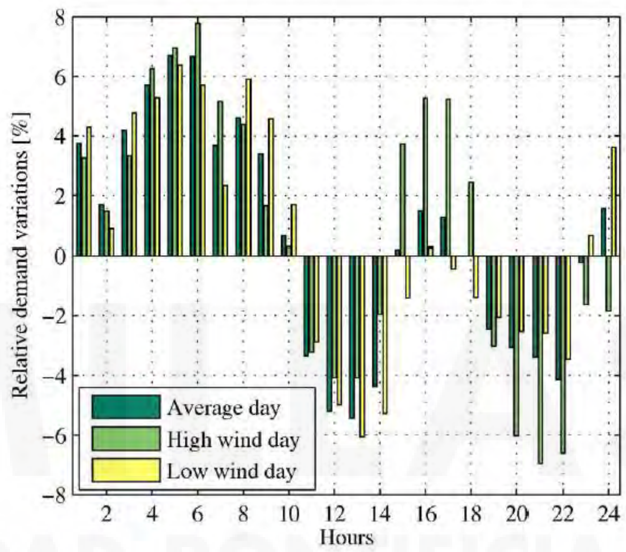


Iso-RES curtailment curve



Demand Response (DR)

- DR driven by electricity price with direct load control



Demand shifting in centralized model on different wind days.

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Thank you for your attention

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