TASK 5– ENVIRONMENT & ECONOMICS – DEFINITION OF BASE CASE

PART 1: ECONOMIC AND ENVIRONMENTAL VALUE OF SMART APPLIANCES' FLEXIBILITY FOR THE ELECTRICAL ENERGY SYSTEM

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Content

1. Goal

- **Evaluate the economic and environmental value of smart appliances flexibility for the electrical energy system**
- 3 main KPIs will be calculated:
  - Environmental value:
    1. Efficiency of generation mix → increased utilization of RES
    2. Reduction of CO_2 emissions
  - Economic value: Reduction in total system costs

2. Use Cases for Flexibility from Smart Appliances

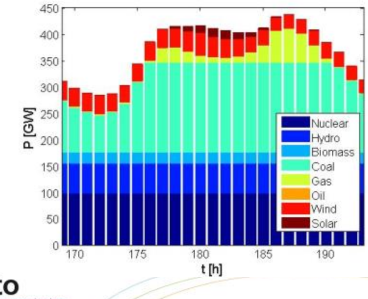
- Two use cases are distinguished (what can the flexibility be used for?):
  - **Day-ahead use case**: optimization of the day-ahead scheduling of electricity production and consumption
  - **Imbalance/reserve use case**: real-time matching of supply and demand

2. Use Cases

- **Day-ahead use case**:
  - Based on the estimated consumption, BRPs adapt their production volume and/or buy on the exchange the needed volumes to match supply and demand
    - Demand response can participate directly on the exchange
    - Demand response can be used directly by the BRP to optimize its production schedule
  - The presence of demand response will enable to avoid electricity production with expensive and polluting power plants during certain hours
    - Hours with low wind and solar
    - Hours with structural high consumption (morning peak/evening peak)
    - Hours during seasons with higher consumption (very cold days during winter)

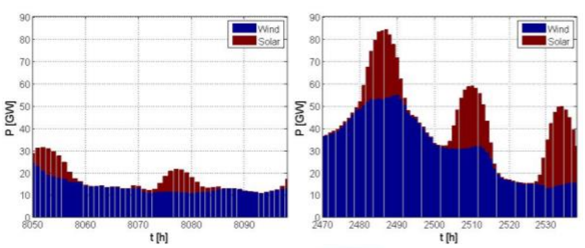
2. Day-ahead use case – peak shaving

- EU 28



2. Day-ahead use case – integration renewables

- 3 days (week 47 vs week 15)

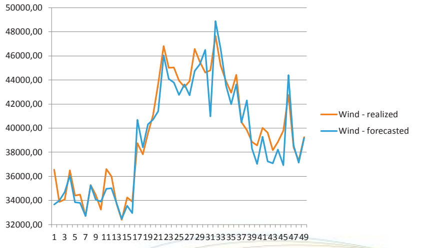


2. Use Cases

- **Imbalance use case**:
  - In real-time, deviations are observed between supply and demand
  - Primary origin: changing weather conditions (temperature, wind, …), but also sudden outages of dominant power plants → **forecast errors**
  - In theory – deviations cannot be forecasted beforehand
  - Deviations can be solved by:
  - (1) TSO who activates ancillary services (reserves) – BRPs receive a penalty for their imbalance
    - FCR = frequency containment reserve – fast reserve – 15 sec response time, **continuous** (less suited for smart appliances except batteries)
    - FRRm and FRRa = frequency restoration reserve – slower response time, limited duration
  - (2) BRPs can try to solve directly their imbalances by activating reserves from their own portfolio

2. Imbalance/reserve use case

» Wind power production and forecast for aggregated EU28 for 2 days in 2014



3. European context

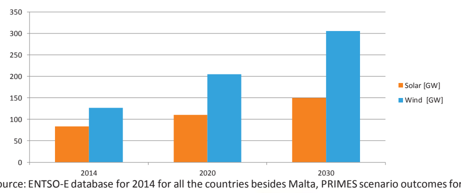
» Installed capacity European Target Model for Market Integration
- Investment in cross border interconnections
- Different markets (day-ahead, intraday, imbalance,…) will be coupled within the EU
- Goal: harmonized market rules and mechanisms and a uniform and competitive price for all markets

» EU 2020 & 2030 objectives
- Significant increase of renewable energy between 2015 and 2030

3. Assumptions - installed generation

» Predicted installed renewable energy capacity – EU 2020 & 2030 objectives
- Significant increase of renewable energy between 2015 and 2030

Figure: Installed RES capacity in [GW] for the whole EU-28 area



- Source: ENTSO-E database for 2014 for all the countries besides Malta, PRIMES scenario outcomes for 2020 and 2030, and for Malta for 2014, and for peak load in Malta Enemalta

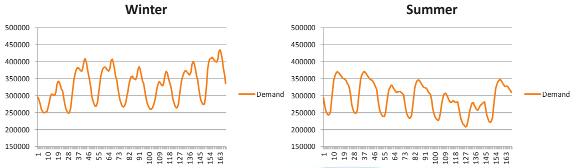
3. Assumptions - generation mix and transmission system

» Installed capacity per country
- Based on ENTSO-E published data of 2014 for EU 28
- Installed capacity in 2020 and 2030 – based on Primes scenario's

» Transmission system
- Not modeled
  - arguments: European energy market target model, further harmonisation

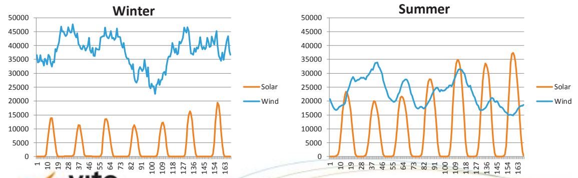
3. Assumptions - demand hourly profiles

» **Demand or Load**
- Based on ENTSO-E published data of 2014 for EU 28
- Corrected for import and export with unmodeled neighboring countries
- Load in 2020 and 2030 – yearly increase of 1,4% is assumed



3. Assumptions - RES hourly profiles

» **Wind and Solar Power**
- Based on ENTSO-E country historical data (country TSO webpage)
- For countries that do not publish such profiles, an estimation based on neighboring countries is used
- 2020 and 2030 - increase proportional to the increase of the installed capacity is assumed (same load factor)



3. Assumptions - Fuel prices

» Prices remain relatively stable between 2014 and 2020

» In 2030 expectations are that mainly the price of CO_2 will have risen significantly → impact on profitability of thermal plants and system costs

» Price for biomass will rise as well as it is expected that biomass will not be subsidized

Fuel	2014	2020	2030
Nuclear [EUR/MWh_prim]	6,34	6,34	6,34
Coal [EUR/MWh_prim]	8,42	11,93	11,97
Natural gas [EUR/MWh_prim]	25,75	31,66	32,71
Wood pellets [EUR/MWh_prim]	5,06	4,84	30,08
Oil [EUR/MWh_prim]	48,48	53,54	57,42
CO2 [EUR/tCO2]	5,96	9,07	48,00

Sources: realised market prices as published by ICE Endex & knoema for 2014; IEA scenario's for 2020 and 2030 scenario's; CO2 estimate for 2030 from Thomson Reuters

3. Assumptions – modelled smart appliances

» Modelled smart appliances:
- Washing machines
- Tumble dryers
- Dishwashers
- Refrigerators and freezers
- HVAC heating in residential and tertiary buildings (electric heating)
- HVAC cooling in residential and tertiary buildings (air conditioning)
- Residential energy storage system

3. Assumptions – not modelled smart appliances

» Not modelled smart appliances (see results of Task 1):
- Washer-dryers – high potential, but no data (amount? profiles?)
- Commercial refrigeration products - no data (amount? profiles?)
- Water heaters (continuous) – high potential, no data
- Lighting – low potential
- HVAC ventilation – low potential
- Behavioural appliances – low potential
- Battery operated rechargeable appliances (low power) – low potential

4. Model description

» Unit commitment model – optimize schedule of the dispatchable units so that the total system costs are minimized

» Power demand (given) has to be matched by power production (RES – given, dispatchable units – schedule to be optimized)

» Technical and economic properties of dispatchable units (nuclear power plant, gas fired, coal fired,…) are modelled:
- » Efficiency, start up and shut down rate, ramp up and down time, …
- » Variable and operational costs, Start up and shut down costs, …

4. Model input and output data

Inputs
- Amount of smart appliances (Task 2)
- Hourly profiles of flexibility from smart appliances (per group) and maximal average shifting times (Task 3)
- Hourly profiles of demand and hourly profiles of renewables (Task 3)
- Fuel and CO_2 prices (Task 3)
- Installed generation capacity per generation technology (Task 3)
- Technical and economic parameters per generation technology
- Imbalance volumes (forecast errors)

Model
- Constrained optimization

Outputs
- Total system costs (per hour)
- Marginal prices per hour
- CO_2 emissions per hour
- Production mix per hour
- Optimal utilization of flexibility from smart appliances

4. Model – flexibility model

» Flexibility definition (task 1):

The demand response potential of a group of appliances is defined by two parameters:
- a **shifting potential** = the amount of energy that can be shifted, expressed in [MWh/h] → hourly flexibility profiles utilized to represent the shifting potential
- **average maximal shifting period =** the maximum number of hours [h] that the demand of the appliance can be shifted, i.e., to consume later/earlier in time than initially planned

» **Output of tasks 1 - 3** used to model flexibility (e.g., used: number of smart appliances, clustered hourly flexibility profiles per smart appliance group,…)

5. Remuneration mechanisms

(Described in Task 2)

- Remuneration mechanisms provide **incentives** to use the flexibility of smart appliances
- The choice of remuneration mechanism will determine how much of the entire flexibility value of smart appliances will be captured
- The remuneration mechanism will transfer the value generated by the flexibility of smart appliances to the consumer
- The value of the flexibility of smart appliances will be distributed across the entire value chain via other mechanisms (e.g. purchase price of smart appliances)

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5. Remuneration mechanisms

- Several remuneration mechanisms exist:
  - **Time-of-Use:** a set of time-blocks during the day (3-6 hours) with predefined prices for each block
  - **Critical Peak Pricing:** during a limited number of days (critical events), the price is significantly raised during certain hours
  - **Real Time pricing:** pricing based on real-time day ahead or imbalance prices
- Remuneration mechanisms can be based on **manual** or **automated** control
- In theory, a RTP-mechanism, in combination with automated control will allow smart appliances to maximally respond to system needs (and capture the maximum value)

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5. Remuneration mechanisms – Coupling the KPIs and the remuneration mechanisms

- The value of the KPI 'reduced system costs' equals the value captured via an automated RTP mechanism
- Results will show for both use cases when the flexibility of smart appliances is used in each of the use cases
  - Day –ahead
  - Imbalance
- Depending on the results of RTP mechanism, determine whether other remuneration mechanisms will be useful and modeled

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5. Remuneration mechanisms

- Factors for a successful remuneration mechanism:
  - Remuneration mechanism is **clear** and **understandable**
  - **Price updates** and events to be announced **in time**
  - Financial incentives should be **high enough**
  - Need for **additional incentives** to support behavioral change
  - **Manual control** during learning phase (user acceptance)
  - **Automated control** needed in case of complex remuneration mechanisms

Source: www.**s3c-project**.eu

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5. Remuneration mechanisms

- Remuneration mechanism for use cases described
  - Should take the 'state-of-the system' into account
  - For the **day-ahead use case**: **RTP**, or combination of **TOU** with **CPP**
    - structural change of daily consumption pattern
    - additional incentive in case of extreme events
  - For the **imbalance use case**: only **RTP** is relevant
    - continuous response on market deviations (no patterns available)
- Smart remuneration mechanisms allow to optimize self consumption

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5. Remuneration mechanisms - examples

- Today, dynamic pricing mechanisms mainly developed in countries with a need for demand response
  - High share of renewable energy (e.g. Nordic countries, Germany, Belgium, Italy)
  - High share of electric heating (e.g. France)
- Examples:
  - **RTP**: In Sweden, energy suppliers offer RTP to households since 2012
  - **Critical peak pricing**: France (EDF) offers product where on a daily base, a colour code, reflecting the state of the system determines the price
  - **TOU**: Pilot project Linear: 6 fixed time blocks, price is determined every day for the next day
  - **Alternative pricing**: US (Austin Energy and CPS Energy offered a free thermostat in exchange for the control of the air-conditioning

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5. Cost-Benefit estimation for the end user

- Potential additional costs for the end consumer:
  - Potentially higher price for the appliance for redesign of the DR enabling
  - Additional energy consumption (communication, control…)
  - Extra efforts, possible comfort loss
- End-user will balance remuneration for providing flexibility against additional costs

How do the **economic benefits at grid side**
(provided by an appliance over its lifetime = output model)
relate to
the **additional costs for end-user**?

Is the economic value of flexibility from an energy system perspective large enough e.g. to remunerate end-users and thus stimulate take-up of smart appliances?

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6. Conclusions

- Two use cases relevant for smart appliances: day-ahead market and imbalance market
- For battery systems, an additional use case is relevant (e.g. participation to the FCR market)
- Smart remuneration mechanisms provide the proper incentives to make use of the flexibility potential of smart appliances

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6. Future work – next steps

» Finalisation of data collection Tasks 2, 3 and 4 as input for modeling

» Sensitivity analysis
- Identify the most uncertain input parameters
- Define realistic ranges of these parameters
- Run the sensitivity analysis

» Coupling the remuneration mechanisms to the KPIs

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