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 CO₂ 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)

> 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

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 scenarios
- 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

<table>
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<th>Fuel</th>
<th>2014</th>
<th>2020</th>
<th>2030</th>
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<tr>
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<tr>
<td>Oil</td>
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</tbody>
</table>

Sources: realised market prices as published by ICE Endex & knoema for 2014; IEA scenarios for 2020 and 2030 scenarios; 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 CO₂ 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
- CO₂ 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] \rightarrow 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)

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)

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

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](http://www.s3c-project.eu)
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

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)

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?

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
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