TASK 6 – ENVIRONMENT & ECONOMICS – DEFINITION OF FLEXIBLE CASE

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Content

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1. Goal - research questions

- How can flexibility provided by smart appliances support the energy power system and what is the value of the flexibility of smart appliances to the system?
- What is the value of smart appliances for the environment (better integration of RES, primary energy savings)
- What is the value for the end user?
- How do these benefits compare to the costs of smart appliances?
- What are the value and costs for the industry?

2. Model – modelled smart appliances

- Washing machines
- Tumble dryers
- Dishwashers
- Electric storage water heaters
- Refrigerators and freezers (residential and commercial)
- HVAC heating in residential and tertiary buildings (electric heating – electric radiators, boilers, heat pumps)
- HVAC cooling in residential and tertiary buildings (air conditioning)
- Residential energy storage system

2. Model – not modelled smart appliances

- Washer-dryers: high potential, but no data, limited # of smart appliances compared to other groups of smart appliances
- Lighting: low potential
- HVAC ventilation: low potential
- Behavioural appliances: low potential
- Battery operated rechargeable appliances (low power): low potential

2. Model – flexibility model

» Definition of flexibility (see Task 1):

The demand response potential of a group of appliances is defined by:

- 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 1-2-3** used to model flexibility (e.g. number of smart appliances, clustered hourly flexibility profiles per smart appliance group)

2. Model – shifting potential captures (Task 3)

- **Seasonality:** the amount of energy that can be shifted differs with season for all the groups - besides dishwashers, washing machines, residential refrigerators and freezers
- **Climatic zone:** the effects on the **amount** of flexibility from smart appliances due to the different climatic conditions are considered for the relevant appliances
- **Time zone:** hourly flexibility profiles of countries in different time zones are shifted to match with the defined model time zone

2. Model – groups of flexibility

» Several flexibility groups made due to:
- Different models (storage vs demand shifting)
- Different shifting times (less than 1h, 1h, 3h)
- Additional technical constraints

» Definition of groups:
- Group 0: First order storage model with losses
- Group 1: Demand shifting, 3h
- Group 2: Demand shifting, ≤ 1h
- Group 3: Demand shifting, 1h, with minimum down time constraint

2. Model – groups of flexibility - overview

Smart enabled appliances		Group
Periodical appliances	Dishwashers	Group 1
	Washing machines	Group 1
	Tumble dryers	Group 1
Energy storing appliances	Refrigerators and freezers (residential)	Group 2
	Electric storage water heaters	Group 2
Residential heating and cooling	HVAC residential cooling (heat pump)	Group 3
	HVAC residential heat pump heating	Group 3
	HVAC residential Joule heating	Group 3
Tertiary heating and cooling	HVAC tertiary cooling (heat pump)	Group 3
	HVAC tertiary heat pump heating	Group 3
	HVAC tertiary Joule heating	Group 3
Commercial refrigeration	Tertiary cooling (evaporator, compressor)	Group 2
Residential energy storage systems	Home batteries	Group 0

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3. Assumptions – amount of enabled smart appliances (see Task 2)

Smart enabled appliances		2014	2020	2030
Periodical appliances	Dishwashers	0%	2%	8%
	Washing machines	0%	1%	4%
	Tumble dryers	0%	2%	16%
Energy storing appliances	Refrigerators and freezers (residential)	0%	5%	20%
	Electric storage water heaters	0%	5%	20%
Residential heating and cooling	HVAC residential cooling (heat pump)	5%	18%	54%
	HVAC residential heat pump heating	5%	18%	54%
	HVAC residential Joule heating	0%	3%	21%
Tertiary heating and cooling	HVAC tertiary cooling (heat pump)	5%	18%	54%
	HVAC tertiary heat pump heating	5%	18%	54%
	HVAC tertiary Joule heating	0%	3%	21%
Commercial refrigeration	Tertiary cooling (evaporator, compressor)	0%	10%	50%

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3. Assumptions – residential storage appliances

Installed energy capacity of home batteries (only in Germany), source: B. Normark et al, "How can batteries support the EU electricity network?", technical report, 2014

Year	Charging rate [MWh/h]	Energy capacity [MWh]	Efficiency η [%]	Number
2014	16,83	43,0	85	6000
2020	25,25	64,5	85	9000
2030	42,08	107,5	85	15000

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3. Assumptions – cfr Task 5

- Two use cases:
  - **Day-ahead use case**: optimisation of the day-ahead scheduling of electricity production and consumption
  - **Imbalance/reserve use case**: real-time matching of supply and demand

- 3 main KPIs calculated:
  - Environmental value:
    1. **Efficiency of generation mix** (primary energy savings) → decreased utilization of peaking units, increased utilization of RES
    2. **Reduction of CO_2 emissions**
  - Economic value: **Reduction in total system costs**

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3. Assumptions – flexibility in short

Share of flexible demand in the total demand over the benchmark years

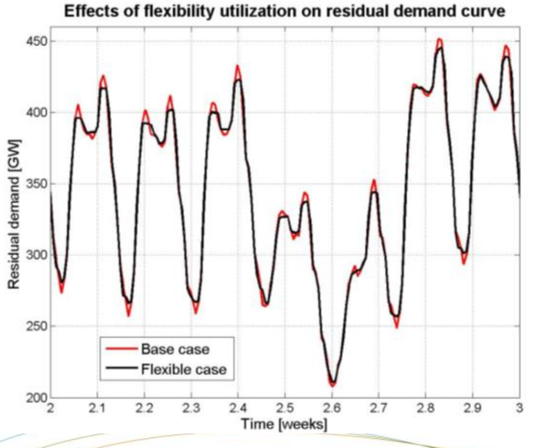
Year	Share of flexible demand energy [GWh/GWh]	Share of peak flexible demand [MW/MW]	Peak flexible power in the EU-28 area [GW]
2014	0,1%	0,9%	2,8
2020	0,8%	3,4%	10,6
2030	3,4%	10,3%	37,7

4. Flexible case – effects of flexible demand

» Flexibility is used to flatten the peaks in residual demand curve in the day-ahead use case:

- during the peak hours: around noon, and in the late afternoon hours
- during the low residual demand peak, which is typically in the night, 2 - 5am

» Figure shows the EU-28 area, for a winter week, scenario for 2030



4. Flexible case – day-ahead use case – results

- Differences in KPIs between the flexible and base case determines the net impact of flexibility
- System costs decrease when smart appliances flexibility is utilized → in particular in 2030 scenario (high CO_2 emission price)
- Small savings in CO_2-emissions, due to lower use of fossil-fuel fired generation units (< 1% of total CO2 emissions day ahead base case)
- Increase efficiency generation mix: lower share of peaking units

Day ahead use case	ΔKPI1 (savings in total system costs) [M€]	ΔKPI2 (savings in CO_2 emissions) [kt]	ΔKPI3 (primary energy savings) [%]
2014	8,8 M€	60 kt	0,01%
2020	54,5 M€	770 kt	0,05%
2030	1710,5 M€	3880 kt	0,29%

4. Flexible case - results

- System savings given as percentage of the total system costs over the years
- **More flexibility from smart appliances → more system savings**

	Savings as % of the total costs	Share of flexible demand in the total demand (energy-wise)
2014	0,01%	0,1%
2020	0,07%	0,8%
2030	1,48%	3,4%

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4. Flexible case - results

» Marginal electricity prices for the day-ahead use case tend to decrease due to utilization of flexibility → **benefits for all end users**

	flexible case [€/MWh]	base case [€/MWh]
2014	42,62	42,70
2020	52,91	52,94
2030	92,97	97,03

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4. Flexible case - results for individual appliances

» Step-wise approach to calculate the value per appliance:

1. Total benefits (ΔKPI1) are distributed across all flexibility groups based on optimal shifted flexible demand profile
2. For each group of flexibility (groups 0-3), the value is allocated to individual appliance groups based on the average energy consumption per group, i.e. the higher the average energy consumption, the higher the allocated value (due to the higher shifting potential)
3. Benefits per appliance group are divided by the number of smart enabled appliances

Preliminary results –

Methodology to be further refined based on inputs from the stakeholder meeting

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4. Flexible case – value per flexibility group

Expressed as savings per shiftable energy capacity €/MWh

year	Group 0 (storage) [€/MWh]	Group 1 (3h) [€/MWh]	Group 2 (1h) [€/MWh]	Group 3 (1h extra) [€/MWh]
2014	3,4	0	0	2,0
2020	3,8	6,0	3,2	1,6
2030	34,5	34,1	13,3	13,9

→ **The higher average shifting time, the more value**

→ **Value of one flexibility type is dependent on the presence of other flexibility types in the system (both from smart appliances and other sources, such as industrial processes)**

4. Flexible case – Economic value per appliance

Value of benefits per enabled smart appliance per year		2014	2020	2030
Periodical appliances (Group 1)	Dishwashers	0€	17,2€	7,5€
	Washing machines	0€	1,2€	6,4€
	Tumble dryers	0€	4,0€	10,5€
Energy storing appliances (Group 2)	Refrigerators and freezers (residential)	0€	0,2€	1,1€
	Electric storage water heaters	0€	1,2€	6,4€
Residential heating and cooling (Group 3)	HVAC residential cooling (heat pump)	0,8€	0,9€	11,2€
	HVAC residential heat pump heating	1,0€	1,2€	14,5€
	HVAC residential Joule heating	0€	1,9-15,0€	9,6 – 75,6€
Tertiary heating and cooling (Group 3)	HVAC tertiary cooling	14,7€	17,0€	208,1€
	HVAC tertiary heat pump heating	6,2€	7,3€	88,7€
	HVAC tertiary Joule heating	0€	1,8-14,4€	9,7 – 77,1€
Commercial refrigeration (Group 2)	Tertiary cooling (heat pump)	0€	1,5€	29,2€
Residential energy storage systems (Group 0)	Home batteries	212,6€	235,6€	2160,4€

→ **Expressed per household, value can become interesting…**

4. Flexible case – Sensitivity analysis

- Assumptions → adapted flexible case:
  - All periodicals can be shifted for 6h instead of 3h
  - The HVAC heat pumped based devices can shift for 6h (instead of 1h with an additional constraint)
- Energy and power amount of flexibility is the same, nevertheless there is an increase in available flexibility
- Changes in assumptions of maximum average shiftable time lead to a considerable increase in value of smart appliances

Day ahead use case	ΔKPI1 (savings in total system costs – flexible case) [M€]	ΔKPI1 (savings in total system costs – sensitivity adapted flexible case) [M€]	Increase in savings in system costs [%]
2014	8,8 M€	**28,6 M€**	225,0%
2020	54,5 M€	**89,2 M€**	63,7%
2030	1710,5 M€	**2554,4 M€**	49,3%

4. Flexible case – imbalance use case – results

- Differences in KPIs between the flexible and base case determines the net impact of flexibility
- System costs decrease when smart appliances flexibility is utilized → in particular in 2030 scenario (high CO_2 emission price)
- Small savings in CO_2-emissions, due to lower use of fossil-fuel fired generation units
- Increase efficiency generation mix: lower share of peaking units

	KPI1 (total system costs) [M€]	ΔKPI1 (savings in total system costs) [M€]	KPI2 (CO2 emissions) [Mt]	ΔKPI2 (savings in CO2 emissions) [kt]	KPI3 (efficiency of the utilized gen. mix) [%]	ΔKPI3 (primary energy savings) [%]
2014	5,6	1,6	1,6	10	54	0,00
2020	9,8	1,4	1	610	58	0,03
2030	12,2	131,5	0	1780	61	0,29

5. Evaluation of costs and benefits for energy system

- Yearly benefits of smart appliances should be compared with the additional annualized investment costs and yearly operational costs to enable their flexibility
- Costs of the entire value chain of smart appliances need to be taken into account
- In the model, benefits are assumed to be directly remunerated towards the end-consumer
- However, in real life part of the allocated value will be passed through to other partners (e.g. manufacturers,…) in the value chain via the prices they charge towards the end consumer for their services
- Final benefits awarded to the end consumer depend on market power, subsidy systems, sector rules, EU regulation, … (out of scope)

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5. Evaluation of costs and benefits for energy system

- Benefits smart appliances:
  - Optimization planning in **day-ahead**
  - Support the system in real-time in case of insufficient production (**negative imbalance**)
  - Support the system in real-time in case of overproduction from RES (**positive imbalance**)
- As a result, smart appliances:
  - Support the **integration of RES**, the **decrease in CO_2 emissions** and a **reduced cost of energy production**
  - Support the **increase in self consumption** (batteries in combination with solar panels)
- Additional use cases exist (e.g. TSO-DSO relief in grid congestion), but are not yet mature → expected to become promising in the near future

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5. Evaluation of costs and benefits for energy system

- Example **TSO-DSO congestion relief**:
  - Increased risk of congestion DSO-grid:
    - increase in peak demand
    - increase in RES (mainly connected to the distribution grid)
  - Flexibility could be alternative for investment in additional lines (avoided capex expenses)
  - Flexibility could be an alternative for RES curtailment
  - Today – none of the DSOs in Europe make use of flexibility
  - Main **barriers** :
    - Regulatory framework DSOs:
      - Not incentivized to use flexibility as an alternative due to the remuneration mechanism of DSO costs
    - Lack of the existence of a 'local market' for flexibilities
    - DSOs need to change from a passive network operator to an active system manager

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5. Cost/benefits industry

- See Task 4 and previous: little cost data available, quantification not possible
- Digital communication/IoT functionality will be common in most appliances from 2020 onwards (Task 2)
- This creates an appliance lifetime link with customer and provides a platform for improved and new services for the customer, including DSF

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5. End-user: financial benefits

- End-consumer appliances, for day ahead
  - Up to 18€/year in 2020
  - Up to 77€/year in 2030
- Imbalance market: same order of magnitude.
- Alternative DSF uses, e.g., grid congestion management or specific additional ancillary services (such as frequency containment reserves), potentially have a much higher value

- Policy choices impact the assumptions of the calculations and have a large impact
  - E.g. strong dependency of value on amount of flexibility:
    - Assume 6h shifting window of periodical appliances, heat pumps and airco, same energy and power
    - Added value increase by 225% in 2014, 64% in 2020, 50% in 2030
  - We will investigate the impact of this and other policy measures in Task 7

- Note: this yearly added value must cover investments and operational costs of all actors in the chain

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5. End-user: costs

- Operational
  - Communication infrastructure: shared, low cost
  - Surplus energy: see later

- Investments
  - See Task 4
  - In general: difficult to derive generalized estimations
  - Mostly in 5-20€ range, but in some cases estimated up to 200€

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5. End-user: energy consumption

- More flex may result in surplus consumption
  - E.g., when cooling deeper, heating higher, …
  - Flex assumptions in study are such that surplus consumption is negligible
  - But: more flex creates a lot of added value (increased RES share, reduced CO2, less use of expensive units), so may still be worthwhile

- Energy efficiency opportunities
  - Studies show that detailed views on energy consumption, combined with energy reduction advice results in final energy savings of typically 5 to 12%
  - DSF functionality can also be used for energy saving optimizations. E.g.:
    - 'Smart control' as defined in Ecodesign requirements for heaters and hot water storage tanks, set via regulation No 814/2013 of 2 August 2013
    - Advice to the user on more efficient operational modes

5. End-user: comfort

- Impact on comfort is strongly device dependent (see Task 3)

- DSF offer opportunities, as the functionality and infrastructure can be shared with home automation applications, e.g., preventive maintenance, improved (app-based) interfaces, etc.

- In an IoT-DSF ready appliance the 'smartness' and infrastructure are shared, as are the costs

5. End-user: other points of attention

- Distribution of costs and benefits
  - Mandatory approach yields lowest extra cost per appliance, but socializes costs among all appliance owners, including those that don't use DSF functionality
  - Non-mandatory avoids this, but surplus cost per appliance will be higher, which may hamper access of less fortunate groups to the added value of DSF appliances
  - Right for/equal access to DR programs is important
- To avoid exclusion of groups without internet access, LPWAN or alternative communication technologies should be considered
- Open standards: it must be possible to use and interchange any smart appliance of any brand/vendor in any DR program to avoid vendor lock-in (appliance manufacturer or energy retailers)

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