ECONOMIC IMPACT OF ENERGY SMART APPLIANCES IN THE CONTEXT OF THE BROADENED SCOPE OF THE STUDY

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1. Goal

- What is the technical potential and economical/environmental effects of the energy smart appliances, including electric chargers, in Norway, Iceland, Switzerland and Lichtenstein?

- What is the technical potential of electric chargers in EU and EEA countries in the context of demand response as defined in the phase 1 of the study?

- What are other relevant issues related to electric chargers and electric vehicles in the context of demand response?

2. Electric personal vehicles – preliminary analysis

- Component-based system:
    - Battery in the EV
    - Charging poles – infrastructure

- 3 core components of the energy smart appliance:
    - Flexibility – in battery, when connected to the charging point
    - Control – in the charging point
    - Power consumption – in battery, when driving

- No ecodesign or energy labelling defined for any of the components

2. Electric personal vehicles – market analysis

- EV market defined by:
  - Vehicle and battery characteristics
  - Infrastructure characteristics
  - System services design characteristics
- Many scenarios in literature, *e.g. Reiner R. et al, "Challenges for a European Market for Electric Vehicles", 2010, or IEA, "Global EV Outlook 2016, beyond one million electric cars"*
  - The Directorate-General for Internal Policies
    - Scenario 1 (no globally binding CO_2 targets, a moderate increase of oil prices).
    - Scenario 2 (agreement on climate policy, a continuous increase of oil prices and utilities investing in charging infrastructure).
    - Scenario 3 (globally binding CO_2 targets and a thorough climate change policy, Oil prices increase to $200/barrel, utilities and OEMs invest in charging infrastructure, stimulating policies for Evs).

2. Electric personal vehicles – market analysis

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Scenario 2, EU-28	Total volume in 2020	Total volume in 2030
ICE	51.205.000	45.548.000
HEV	9.975.000	10.036.000
PHEV	3.325.000	15.440.000
BEV	1.995.000	6.176.000

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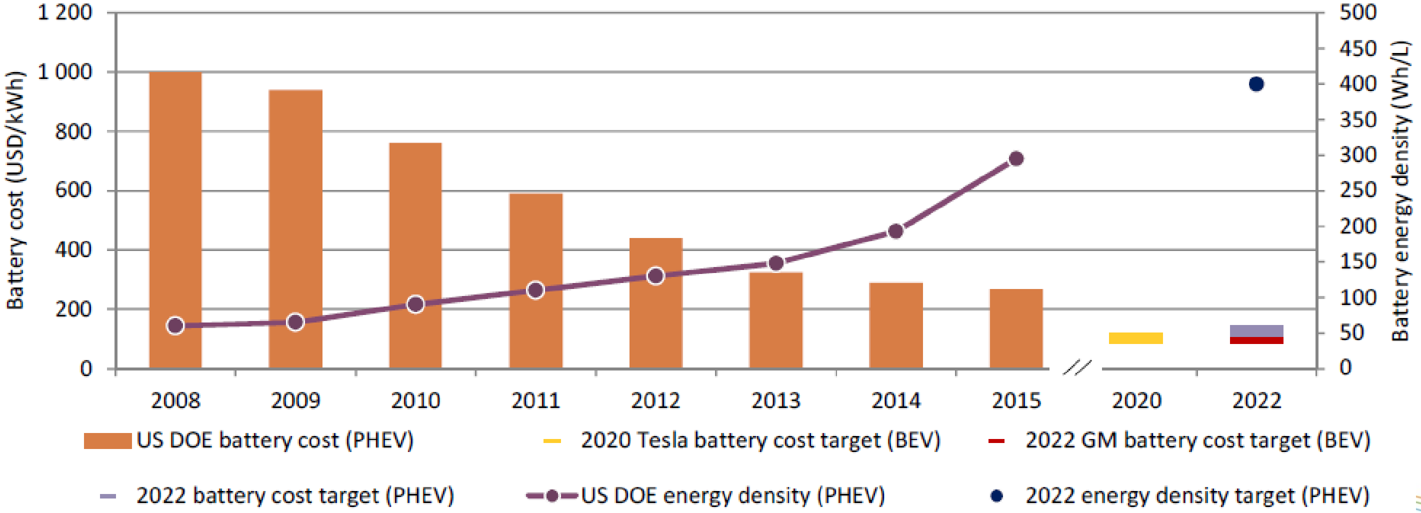
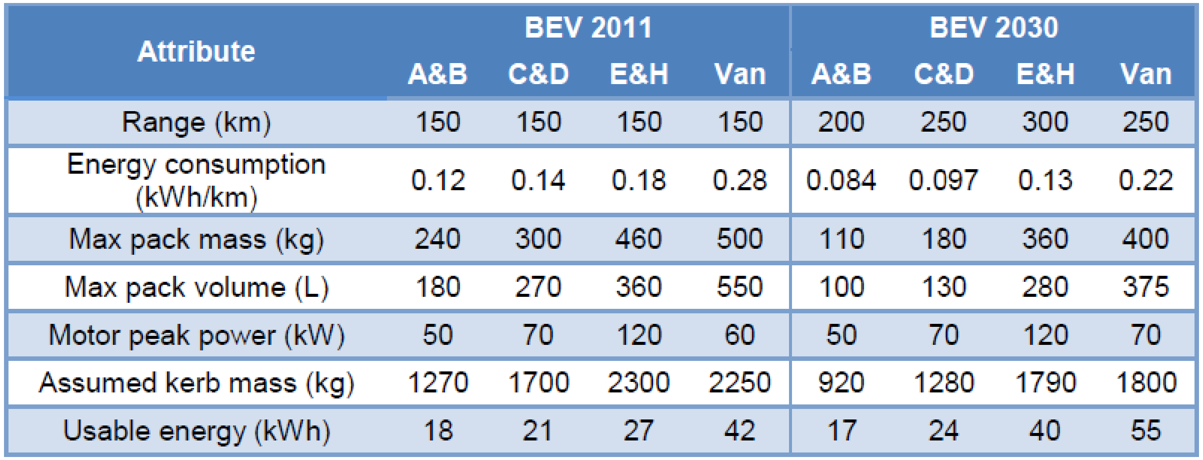
2. Electric batteries for personal vehicles – market analysis

- Rapid cost declines and performance improvements in the past decade due to:
    - Technology learning,
    - RD&D and
    - mass production.
- Expected to continue to progressively reduce technology costs in the near future (source: IEA, “Global EV Outlook 2016, beyond one million electric cars”)



2. Electric batteries for personal vehicles – market analysis

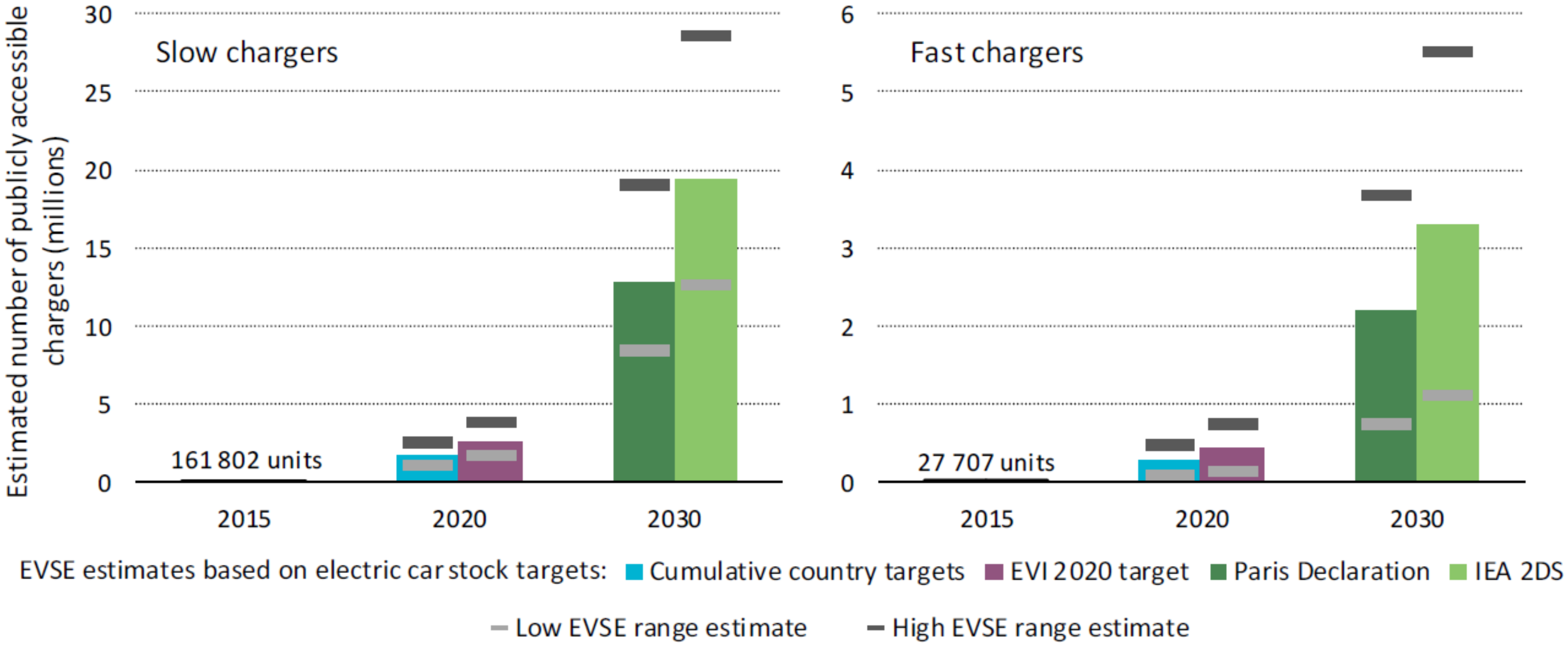
- Rapid cost declines and performance improvements in the past decade due to:
  - Technology learning,
  - RD&D and
  - mass production.
- Hard numbers (source: “Cost and performance of EV batteries”, Final Report for the committee on Climate Change)



Attribute	BEV 2011				BEV 2030			
	A&B	C&D	E&H	Van	A&B	C&D	E&H	Van
Range (km)	150	150	150	150	200	250	300	250
Energy consumption (kWh/km)	0.12	0.14	0.18	0.28	0.084	0.097	0.13	0.22
Max pack mass (kg)	240	300	460	500	110	180	360	400
Max pack volume (L)	180	270	360	550	100	130	280	375
Motor peak power (kW)	50	70	120	60	50	70	120	70
Assumed kerb mass (kg)	1270	1700	2300	2250	920	1280	1790	1800
Usable energy (kWh)	18	21	27	42	17	24	40	55

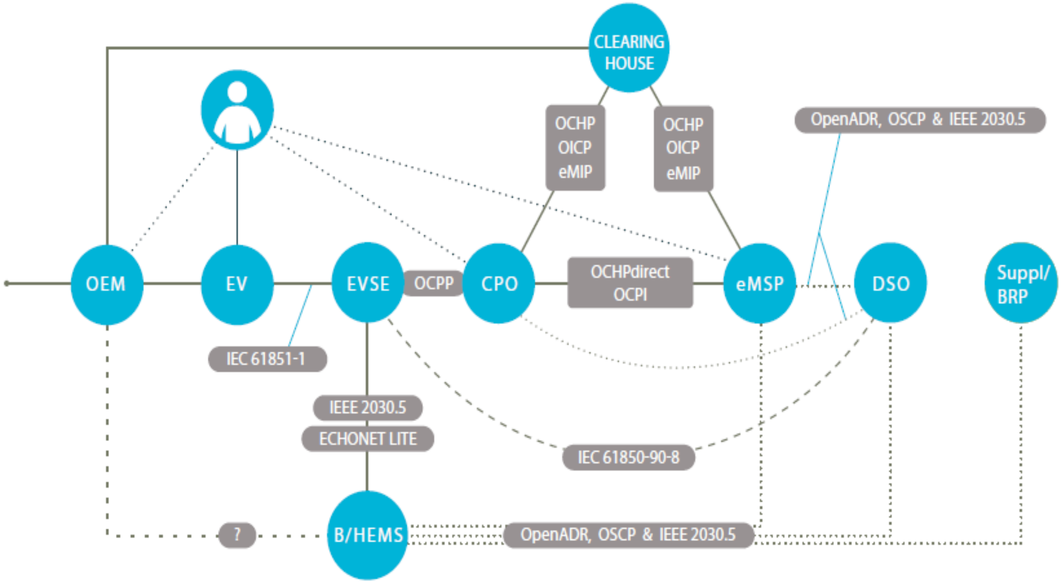
2. Infrastructure for personal vehicles – market analysis

- Electric vehicle supply equipment (EVSE) deployment targets implied by deployment targets for EVs, with EV/EVSE ranges maintained constant at 2015 level (source: IEA, “Global EV Outlook 2016, beyond one million electric cars”)



2. Interoperability of EVs and EV chargers

- Overview of different protocols used between the different electric mobility market actors (source: E-laad.nl)



- Many initiatives: CEN/CENELEC, IEC, SAE, IEEE, OpenADR, EEBus…
- **Standardisation is an important part to reach interoperability**

2. Impact of interoperability of EVs on flexibility potential

- Communicating grid limits or dynamic prices already possible (by protocol).
- Barrier: current legislation in most countries is not yet prepared for dynamic pricing or setting grid limits from a power system operator
- To accelerate the uptake of EV flexibility, the state of charge and time of departure should be shared easily between different components of the system.
- State of charge information:
  - On the short term, recommended to focus on open protocols to include OEMs in the EV domain for getting the state of charge.
  - On the long term, the ISO/IEC 15118 protocol seems to be a good alternative for this.
- Time departure information:
  - Communication with the EV user might be necessary → directly or via the EV (ISO/IEC 15118), possibly a new protocol (left to the market)

2. Conclusions on EVs

- EVs potentially have a high flexibility potential.

- Fast charging contains very little to no flexibility, and is therefore not considered further in the economic analysis.

- The publicly available data related to user behaviour, acceptance, and driving profiles is often limited and far from representative

- Market analysis provided useful figures on
  - the number of EVs and expectations on growth in 2020 and 2030
  - number of chargers and expectations on growth in 2020 and 2030
  - average distance per EV/year/country
- These assumptions will be used later in the model to obtain economic and environmental impact analysis of the EV potential.

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3. Model

- **Day-ahead use case**: optimisation of the day-ahead scheduling of electricity production and (flexible) consumption
- 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, reduction of marginal electricity prices**
- 3 scenarios for the reference years 2014, 2020, and 2030 calculated:
  - base case (no flexibility),
  - BAU (with flexibility, no regulation), and
  - 100% scenario (with flexibility, theoretical maximum).

3. Model structure

Inputs

- Hourly profiles of demand and hourly profiles of renewables (Task 3)
- Fuel and CO_2 prices (Task 5)
- Installed generation capacity per generation technology (Task 3)
- Technical and economic parameters per generation technology
- Network topology (transmission system matrix) and transmission lines capacity (Task 5)
- Imbalance volumes - forecast errors (Task 5)
- Amount of smart appliances (Task 2, utilized in Tasks 6 and 7)
- Hourly profiles of smart appliances flexibility (per group) and average shifting times (Task 3, utilized in Tasks 6 and 7)

Model

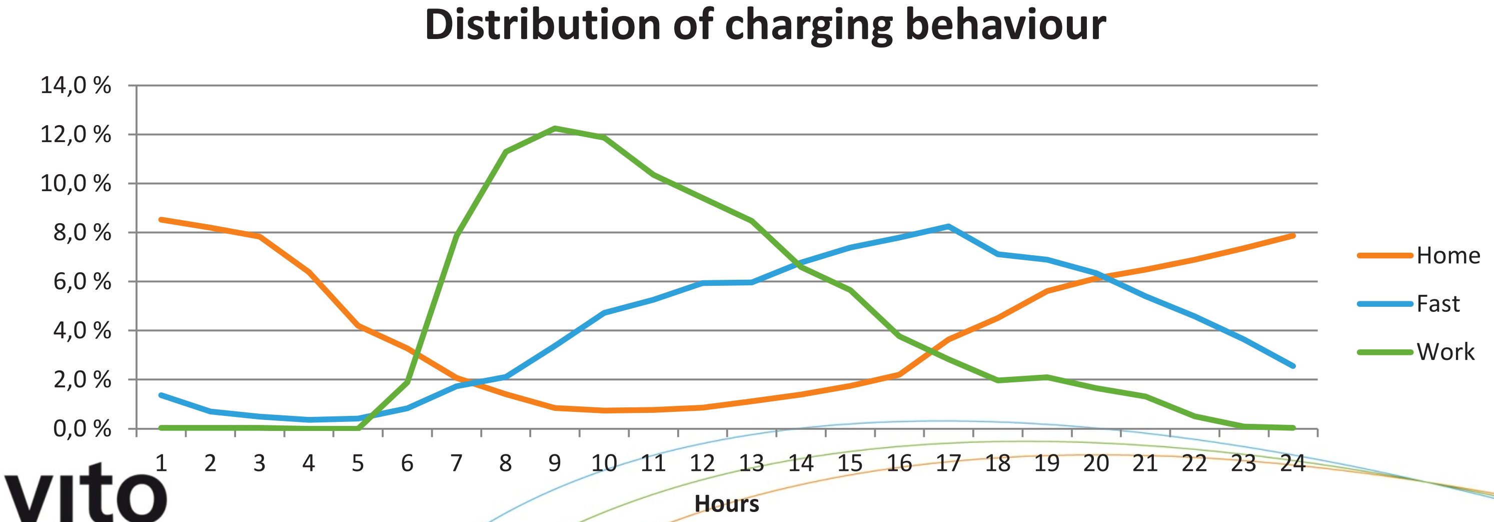
- Constrained optimization (Task 5)

Outputs

- Total system costs
- Marginal prices per hour
- CO_2 emissions per hour
- Production mix per hour
- Optimal utilization of flexibility from smart appliances per hour (in Tasks 6 and 7)

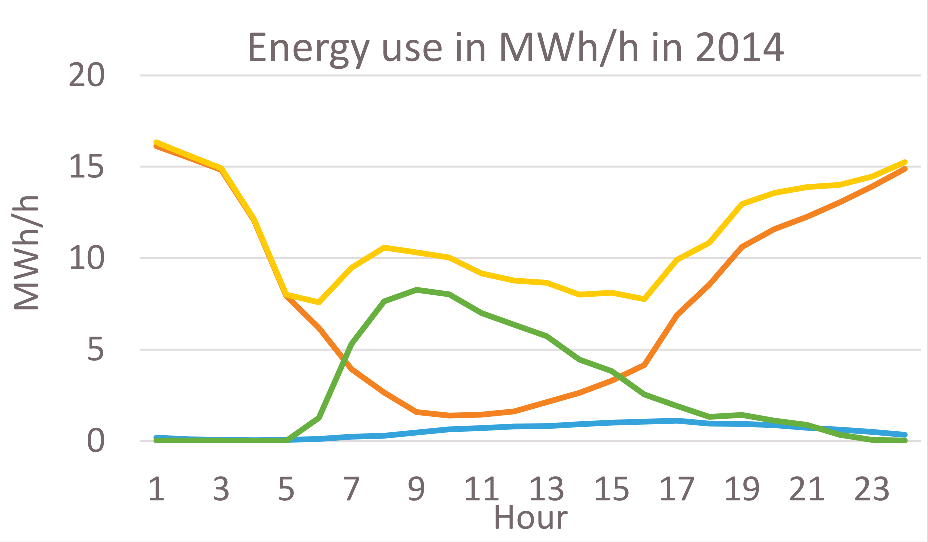
3. Modelling electric vehicles

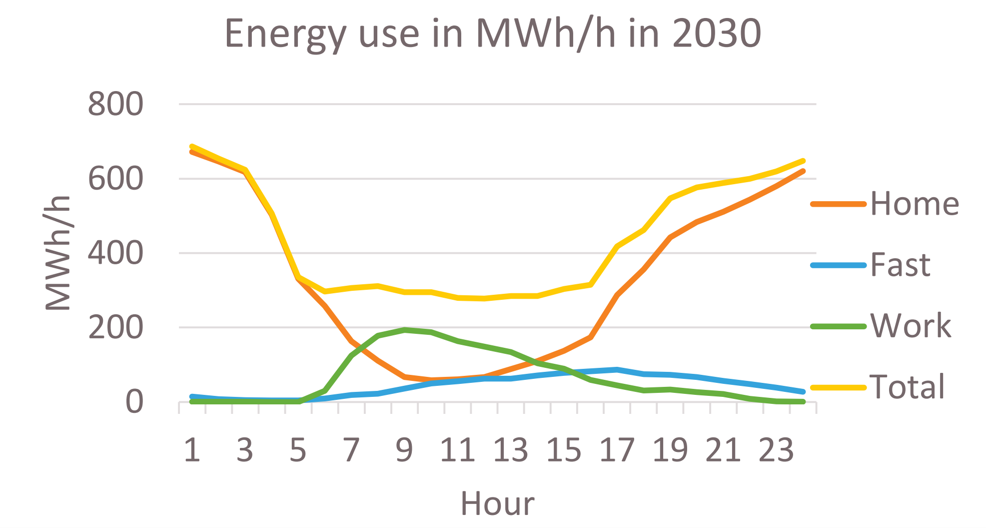
- Aggregated charging of EVs – define the flexibility as shifting potential over time with maximum shifting time.
- Charging needs estimated from
  - Historical data and distribution of charging types over day (slow-home, slow-work), source: NVE
  - Specific energy use per km and driving length per year per country
  - Estimation of number of EVs per country (source IEA)



3. Modelling electric vehicles

- Calculation of aggregated charging needs per country estimated in a simple way (source: NVE)
- Example of charging patterns in Norway for 2014 and 2030





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3. Assumptions – amount of enabled smart appliances

BAU scenario		2014		2020		2030	
Group	Energy smart appliance	#	%	#	%	#	%
Periodical appliances	Dishwashers	0	0	2.300.720	2	11.884.240	8
	Washing machines	0	0	2.008.050	1	8.189.760	4
	Tumble dryers, no heat pump	0	0	718.010	2	622.224	16
	Tumble dryers, heat pump based	0	0	718.010	2	11.822.256	16
Energy storing appliances	Refrigerators and freezers (residential)	0	0	15.400.000	5	63.520.000	20
	Electric storage water heaters (continuously heating storage)	0	0	2.500.000	5	9.100.000	20
	Electric storage water heaters (night storage)	0	0	950.000	5	3.440.000	20
	Tertiary cooling - compressor	0	0	11.501.466	10	70.101.114	50
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	1.053.000	5	3.790.800	18	11.408.963	54
	HVAC cooling, with thermal storage	567.000	5	2.041.200	18	6.143.288	54
	HVAC heating, no storage	104.000	5	374.400	18	1.126.811	54
	HVAC heating, with thermal storage	56.000	5	201.600	18	606.744	54
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	78.000	5	280.800	18	845.109	54
	HVAC cooling, with thermal storage	42.000	5	151.200	18	455.059	54
	HVAC heating, no storage	106.167	5	382.200	18	1.150.287	54
	HVAC heating, with thermal storage	57.167	5	205.800	18	619.385	54
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0	0	6.696.000	3	46.985.342	21
	Electric radiators, with inertia	0	0	555.000	3	3.894.394	21
	Boilers	0	0	30.000	3	210.508	21
Energy storage appliances	Electric vehicles	0	0	2.780.306	50	18.090.086	75

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	37,95	73,6	85	11.500
2020	264	512	85	80.000
2030	676,5	1312	85	205.000

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4. Assumptions related to broadening the study by the EEA countries

- Extrapolation done on basis of EU numbers and scenarios.

- Where possible, national scenarios utilized.

- Extrapolation proportional to
  - number of inhabitants for periodicals and commercial refrigeration,
  - currently present number of EVs for Evs in future scenarios
  - separate analysis for HVAC.

5. Flexible case – two scenarios

- Differences in KPIs between the flexible (BAU or 100%) and base case determines the net impact of flexibility
- System costs decrease when smart appliances flexibility is utilized
- Small savings in CO_2-emissions, due to lower use of fossil-fuel fired generation units and decreased VRES curtailment
- Increase efficiency generation mix: lower share of peaking units

Day ahead use case	KPI1 (total system costs) [M€]		KPI2 (CO2 emissions) [Mt]		KPI3 (efficiency of the utilized gen. mix) [%]		KPI4 (primary energy consumption) [TWh]	
Scenario	BAU	100%	BAU	100%	BAU	100%	BAU	100%
2014	61.961	60.997	748	740	57,8	58,3	3.580	3.546
2020	69.838	68.831	732	725	62,4	63,1	3.086	3.055
2030	94.181	80.231	640	582	64,1	66,3	3.085	2.628

5. Flexible case – relative results

- Differences in KPIs between the flexible (BAU or 100%) and base case determines the net impact of flexibility
- System costs decrease when smart appliances flexibility is utilized
- Small savings in CO_2-emissions, due to lower use of fossil-fuel fired generation units and decreased VRES curtailment
- Increase efficiency generation mix: lower share of peaking units

Day ahead use case	ΔKPI1 (savings in total system costs) [M€]		ΔKPI2 (savings in CO2 emissions [kt]		ΔKPI3 (primary energy savings		ΔKPI4 (primary energy savings) [TWh]	
Scenario	**BAU**	**100%**	**BAU**	**100%**	**BAU**	**100%**	**BAU**	**100%**
2014	23	987	182	8.412	0,0	0,5	1	35
2020	1.451	2.458	13.667	20.481	0,1	0,9	60	91
2030	482	14.433	32.136	89.513	0,3	2,5	4	461

5. 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 in the reference case		Share of flexible demand in the total demand (energy-wise)	
scenario	BAU	100%	BAU	100%
2014	0,04%	2%	0,2%	17,0%
2020	2%	3%	1,4%	17,3%
2030	2%	15%	6,1%	20,1%

5. 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**

	100% scenario	BAU scenario	Base case
2014	44,81 €/MWh	44,92 €/MWh	44,93 €/MWh
2020	56,64 €/MWh	56,75 €/MWh	58,02 €/MWh
2030	61,79 €/MWh	73,67 €/MWh	73,74 €/MWh

5. Flexible case – Economic value per appliance

		2014		2020		2030	
Group	**Energy smart capable appliance**	**BAU**	**100%**	**BAU**	**100%**	**BAU**	**100%**
Periodical appliances	Dishwashers	0	1,3	5,2	1,3	3,6	1,0
	Washing machines	0	0,7	2,9	0,7	2,0	0,5
	Tumble dryers, no heat pump	0	1,4	5,6	1,4	3,7	0,9
	Tumble dryers, heat pump based	0	1,2	4,5	1,1	3,0	0,8
Energy storing appliances	Refrigerators and freezers (residential)	0	0,2	0,6	0,2	0,4	0,1
	Electric storage water heaters (continuously heating storage)	0	0,9	2,4	0,9	2,4	0,7
	Electric storage water heaters (night [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,0
	[illegible] defrost	0	0,6	0,2	0,6	0,8	0,5
Residential cooling and heating (heat pump based)	HVAC cooling, no storage	1,7	0,2	1,4	0,3	0,8	0,3
	HVAC cooling, with thermal storage	14,6	1,5	11,3	1,8	5,4	2,0
	HVAC heating, no storage	22,1	2,8	14,2	2,2	8,3	1,3
	HVAC heating, with thermal storage	156,7	16,4	106,3	13,6	45,9	5,6
Tertiary cooling and heating (heat pump based)	HVAC cooling, no storage	12,3	1,9	11,6	1,4	5,9	0,9
	HVAC cooling, with thermal storage	198,4	19,4	149,0	11,6	47,8	7,4
	HVAC heating, no storage	3,2	0,5	2,5	0,4	1,5	0,3
	HVAC heating, with thermal storage	29,0	3,3	20,2	2,3	9,7	1,2
Joule based tertiary and residential cooling and heating	Electric radiators, no inertia	0	0,2	1,4	0,2	0,8	0,1
	Electric radiators, with inertia	0	0,4	2,2	0,4	1,3	0,2
	Boilers	0	1,8	10,9	1,8	6,6	1,0
Residential energy storage systems	Home batteries	0	14,8	35,5	14,5	26,2	6,6
	Residential electric vehicles	0	8,9	34,7	6,8	17,1	3,9

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

5. End-user: financial benefits

- End-consumer appliances, for day ahead use case
  - 25 - 35 €/year/household with no major flexibility sources (HVAC without thermal storage, EV, solar panels and battery)
  - 25 - 105 €/year/household with all flexibility sources

- Imbalance market: same order of magnitude, but varies for different appliances (some expected to have larger value).

- Alternative DSF uses, e.g., grid congestion management or specific additional ancillary services (such as frequency containment reserves), potentially have a much higher value, but local case, not EU-wide

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

5. End-user: costs

- Operational
  - Communication infrastructure: shared, low cost
  - Surplus energy: negligible

- Investments
  - Mostly in 5-20€ range, but in some cases estimated much lower (2-4 €), or even 0
  - In an IoT-DSF ready appliance the ‘smartness’ and infrastructure are shared, as are the costs
  - See Task 4, phase 1
  - In general: difficult to derive generalized estimations

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5. Cost/benefits industry

- See Task 4 of phase 1: 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

6. Conclusions

- Promising benefits potential of energy smart appliances, especially:
  - HVAC
  - Batteries
  - EVs
- But other energy smart appliances should not be left behind! → also a potential

- Interoperability still a challenge forming a barrier, legislation (tarrifs) in some cases presents a barrier

- Well defined policy package can help mitigate some of the barriers and speed up the uptake.