When are battery electric vehicles economically convenient? A sensitivity analysis based on multi-carrier residential energy system renovation modelling

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Supplementary material

The present document contains detailed complementary information related to the main manuscript. It is organized by firstly describing the extensive modelling process of the exogenous (input) parameters, and by secondly providing additional insights about the model output, which may help in complementing the discussion of the results performed in the main manuscript. The full set of input and results files (a) along with the model code (b) are available on Github at:

a. https://github.com/eNextHub/MARIOU-RESBEV
b. https://github.com/eNextHub/mario_u

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1. Model description

The underlying mathematical formulation of the adopted energy system optimization model relies on the traditional algebraic structure adopted within Input-Output analysis (IOA), getting inspiration from the Rectangular Choice of Technology (RCOT) model proposed by Duchin and Levine [1]. IOA is a widely diffused cost accounting technique, generally adopted for the analysis of national economies as well as for assessing environmental footprints of products along supply chains [2], and constitutes the computational structure of LCA [3]. Such structure allows the model to be flexible to any kind of extension and integration with multiple energy needs and supply technologies and allows for optimal sizing of a domestic energy system and related dispatch strategy selection.

The next paragraphs describe the mathematical structure, the reference energy system used in the proposed modelling exercise, as well as the parameters whose impact on BEV adoption has been assessed. Please refer to Table 1 and Table 2 for the nomenclature.

Table 1. Set of indices

Indices	Symbol
Energy needs	n
Energy commodities	c
Activities	a
Technologies	t
Storage technologies	s
Years	y
Hours	h

Table 2. Exogenous and endogenous parameters

Exogenous parameters	Symbol	Size
Final demand	$\mathbf{Y}$	$\mathrm{n} \times \mathrm{h}$
Specific production matrix	$\mathbf{m}$	$\mathrm{a} \times \mathrm{c}$
Specific intermediate consumption matrix	$\mathbf{u}$	$\mathrm{c} \times \mathrm{a}$
Specific operational costs	$\mathbf{o}$	$\mathrm{a} \times \mathrm{h}$
Specific investment costs	k	$\mathrm{t} \times 1$
Specific CO_2 emissions (related to operation)	e	$\mathrm{a} \times 1$
Specific embedded CO_2 emissions (related to manufacturing)	f	$\mathrm{t} \times 1$
Availability of activity	$\mathbf{A}_a$	$\mathrm{a} \times \mathrm{h}$
Availability of technology	$\mathbf{A}_t$	$\mathrm{t} \times \mathrm{h}$
Discount rate	r	1×1
Special identity matrix - use side	$\mathbf{I}$	$\mathrm{n} \times \mathrm{c}$
Special identity matrix - supply side	$\mathbf{J}$	$\mathrm{t} \times \mathrm{a}$
Endogenous parameters	**Symbol**	**Size**
Total demand (intermediate and final)	$\mathbf{R}$	$(\mathrm{n} \times \mathrm{t}) \times \mathrm{h}$
Deployed capacity	D	$\mathrm{t} \times 1$
Operating capacity	$\mathbf{C}$	$\mathrm{t} \times \mathrm{h}$
Storage state of charge	$\mathbf{B}$	$\mathrm{s} \times \mathrm{h}$
Production of commodities	$\mathbf{X}_{\boldsymbol{c}}$	$\mathrm{c} \times \mathrm{h}$
Production by activities	$\mathbf{X}_{\boldsymbol{a}}$	$\mathrm{c} \times \mathrm{a}$
Production by needs	$\mathbf{S}_{\boldsymbol{n}}$	$\mathrm{n} \times \mathrm{h}$
Production of technologies	$\mathbf{S}_{\boldsymbol{t}}$	$\mathrm{t} \times \mathrm{h}$

1.1. Mathematical formulation

In a general energy system, a selected set t of multi-carrier technologies, along with s storage technologies, are exploited to enable a number a of activities. In turn, such activities are responsible for the supply of a range of c energy commodities: in the adopted modelling framework, the information on the amount of commodities produced is contained in the specific production matrix $\mathbf{m}$. Furthermore, commodities can be consumed by activities themselves (to be interpreted as intermediate demand) and by the final user; while the former transactions are described in the specific intermediate consumption matrix $\mathbf{u}$, the latter are included within the final demand matrix $\mathbf{Y}$. Finally, multiple commodities can compete one another for the fulfilment of the same energy need (needs are indicated with n). The energy needs and, consequentially, the operation of technologies is represented for each hourly time-step h and each year y of the considered time horizon.

The optimization algorithm of the model is oriented to the minimization of the total discounted cost (net present cost, NPC) of the energy system over a period of y years.The algorithm works in *perfect foresight* mode, meaning the energy needs along the whole time horizon are known since the start of the run period. Equation (1) shows the objective function of the model.

$$\mathrm{Obj} \rightarrow \min(NPC) = \min \sum_{\mathrm{t}} \left[\mathrm{k}_t \mathbf{D}_t + \sum_{\mathrm{y}} \frac{\sum_{\mathrm{h}} \mathbf{o}_a \mathbf{X}_h}{(1+r)^y} \right] \tag{1}$$

The total investment cost of the capacity deployed is represented by the term $\mathrm{k}_t \mathbf{D}_t$, where k_t represents a vector of specific investment costs per unit of installed capacity of technology t. The specific operation costs of activities $\mathbf{o}_a$ are multiplied by the related hourly production $\mathbf{X}_h$, then summed over the hourly time-steps h and annualized according to a discount rate r. The model is then subject to a constraint over the energy need supply ($\mathbf{R}$) and demand ($\mathbf{S}_n$) balance, as described by Equation (2). The two supply and demand terms are respectively defined as follows in Equation (3) and (4). The energy balance is complemented by two additional terms:

- the surplus production of renewable technologies (Equation (5)): by means of the $\mathbf{A}_t$ operator, the total production of all the activities performed by a single technology cannot overcome the availability of the technology itself.
- the adjustment applied to the total energy demand driven by specific technologies, such as thermal insulation (Equation (6)). In particular, $\mathbf{D}_{\mathrm{TI}}$ is the installed units of TI technology installed (it can be just 0 or 1 unit) and $\mathbf{Y}_{\mathrm{TI}}$ represents the correction applied to the final demand matrix $\mathbf{Y}$, which is a null matrix except for the *heating* need row.

$$\mathbf{R} = \mathbf{S}_n \tag{2}$$

$$\mathbf{R} = \mathbf{Y} + \mathbf{I} \cdot [\mathbf{u} \cdot (\mathbf{s} \cdot \mathbf{X})] \tag{3}$$

$$\mathbf{S}_n = \mathbf{I} \cdot \mathbf{X}_n \quad (4)$$

$$\mathbf{J} \cdot \mathbf{X} \leq \widehat{\mathbf{D}} \cdot \mathbf{A}_t \quad (5)$$

$$\mathbf{R} = \mathbf{Y} + \mathbf{I} \cdot [\mathbf{u} \cdot (\mathbf{s} \cdot \mathbf{X}_n)] - (\mathbf{D}_{\mathrm{TI}} \cdot \mathbf{Y}_{\mathrm{TI}}) \quad (6)$$

The total demand $\mathbf{R}$, in turn, is equal to the summation of the final demand of needs $\mathbf{Y}$ and of the intermediate demand. The latter represents the energy needed by each technology to operate and is built upon the specific intermediate demand matrix $\mathbf{u}$, which is multiplied by the production matrix $\mathbf{X}_n$. Two additional contributions to the energy balance equation need to be further reported: (i) the surplus production of renewable technologies: their production is not linked to the energy demand but to environmental unpredictability; (ii) the adjustment to be applied to the total energy demand driven by the presence of specific technologies: this is the case of thermal insulation which has been modelled.

Given the definition of maximum available operating capacity by technology ($\mathbf{C}_t$) in Equation (7), the production of commodities by technologies is constrained to be lower than $\mathbf{C}_t$ in every year and hour (Equation (8)):

$$\mathbf{C}_t = (\widehat{\mathbf{J}^{\mathrm{T}} \cdot \mathbf{D}}) \cdot \mathbf{A}_t \quad (7)$$

$$\mathbf{X}_{c,h,y} \leq \mathbf{C}_{t,h,y} \quad (8)$$

where, $\mathbf{A}_t$ is defined as technology availability, which indicates the maximum production technology t can supply in each hour. To manage the state of charge ($\mathbf{B}$) of the storage technologies, two different constraints are set. The first one, Equation (9), avoids to overcharge beyond the nominal capacity, the second instead, Equation (10), fixes a minimum state of charge (depth of discharge, DoD) in order not to overexploit the capacity. The nominal capacity of each storage technology is indicated henceforth as C_s. It is worth noting that all storage technologies are able to perform two activities: to charge and to discharge. In the next two Equations, the subscripts ch and dis identify these two activities.

$$\mathbf{X}_{s,ch} - \mathbf{X}_{s,dis} \leq \widehat{\mathbf{D}_s}\, C_s \quad (9)$$

$$\mathbf{X}_{s,ch} - \mathbf{X}_{s,dis} \geq \widehat{\mathbf{D}_s}\, C_s\, DoD \quad (10)$$

Being the BEV modelled as a storage technology, these last two constraints are also adopted to describe the charge and discharge dynamic of the vehicle battery.

2. Input data

2.1. Energy need profiles modelling

This Section aims at describing the modelling process adopted for deriving the demand profiles of all the energy needs for the Italian context.

The energy demands have been calculated for 28 days with a time step of 1 hour scaling up which, the full year profile has been obtained: these 28 days correspond, in fact, to 4 specific weeks of the year, one representing each season. More precisely:

- the first week corresponds to a winter week (the last week of January, being the coldest week in 2019 in Milan according to the Renewables Ninja database [4], [5]);
- the second week represents the spring season (the first week of May, including an Italian celebration day as May 1st);
- the third instead represents the summer (the last of July, being the coldest week in 2019 in Milan according to the Renewables Ninja database);
- the fourth week stands for the autumn (the first of November, including another celebration day as November 1st).

Some energy demands are affected by seasons and other also affected by the type of day (e.g. the hot water demand changes during weekend, feast day…). With the selection of these specific four weeks, it was possible to consider both daily and seasonal demand variations.

2.1.1 Electricity

One of the principal needs in a house is the presence of electricity to supply to indispensable appliances for the most diverse activities, from cooking to cleaning, from personal care to the simple need to illuminate the environments.

Before describing the model adopted to derive the electricity load curve, it is necessary to describe a previous step: the need for lighting. This is regulated in Italy by the UNI 10.380 regulation [6] which shows the amount of lux required by each type of room. Following this regulation, it’s possible to know the right amount, type and power of bulbs needed. The lux (symbol lx) is the unit of measurement for illuminance, accepted by the International System. One lux is equal to one lumen per m^2. The lux can be therefore defined as the luminous flux per unit of surface. Lux and lumen are units of measurement of two different physical quantities: lux is the unit of measurement of illuminance, while lumens are the unit of measurement of luminous flux. Therefore, by multiplying the lux required by each room for its dimension, it was possible to obtain the desired lumens (Equation (SM 11)).

$$Lumen_i = Lux_i \times m_i^2 \quad \text{(SM 11)}$$

The letter i indicates the typology of room (i.e. bedroom, bathroom...). Their size has been assumed according to statistical values of floor surface. Their sum, returns the total quantity of lumens (Equation (SM 2)).

$$Lumen_{tot} = \sum_{i} Lumen_i \qquad \text{(SM 12)}$$

The number of light bulbs needed for each home has been found as follow:

$$Number\ of\ lamps = \frac{Lumen_{tot}}{Lumen\ of\ single\ lamp} \qquad \text{(SM 13)}$$

Later, in order to calculate the demand for electricity, it was necessary to create a list of appliances that are generally present in the house. Once considered these preliminary assumptions, the electricity load curve was obtained with RAMP, an open-source bottom-up stochastic model for the generation of high-resolution multi-energy profiles [7]. For each appliance has been defined principally the quantity installed, the rated power expressed in Watts, the number of functioning windows to be considered, the total time the appliance is ON during the day, the percentage of total usage time subjected to random variability, the minimum time the appliance is kept on after the switch-ON event, the possible simultaneous accension of equal appliances, the all-day probable time of operation. After the characterization of all the appliances, RAMP returns an yearly electricity demand profile which is the mean of many stochastic profiles with a minute time step, which is then re-shaped in hourly resolution.

2.1.2 Heating

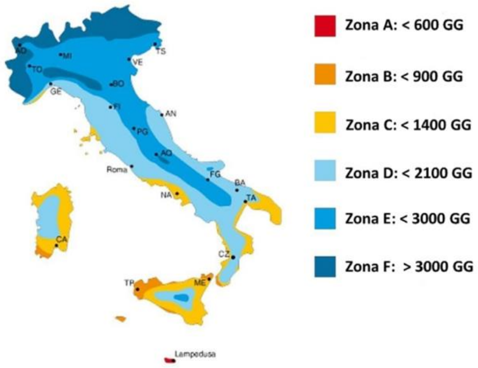
Not being a specific study on space heating, detailed information building thermal exchanges, windows structure and so on have been left out of scope. In particular, the method used for heating demand calculation does not consider:

- the opaque structures that delimit the apartment towards the outside;
- the transparent surfaces outwards;
- the thermal exchanges between nodes;
- the thermal capacity of nodes;
- the injections of thermal power in some nodes, by the plant and other sources (internal inputs, solar radiation…).

Therefore, the thermal balance of the inside air, the thermal zone as convection thermal exchanges, the internal inputs, like direct solar inputs through transparent surface and the flow rate have not been considered.

The work has been focused on a more general method that allows to find the heating requirement, in different buildings and locations, without the knowledge of the previous details. It considers the Italian climatic zones, in accordance with the article 2 of the Decree of the President of the Republic, DPR 412/93. The zones are shown in Figure SM 1a and they are identified depending on the value of degree day (“Gradi giorno” in Italian, indicated with *GG* henceforth). These are defined as: the positive daily differences between 20°C (the conventionally set ambient temperature), and the average daily outside temperature, summed over all days of a conventional annual heating period. Moreover, as shown in Figure SM 1b, specific time conditions in which the heating systems must be activated are defined for each zone.

a)



b)

Fascia	Da[GG]	A[GG]	Ore giornaliere	Data inizio	Data fine	Numero Comuni
A	0	600	6	1° dicembre	15 marzo	2
B	601	900	8	1° dicembre	31 marzo	157
C	901	1400	10	15 novembre	31 marzo	989
D	1401	2100	12	1° novembre	15 aprile	1611
E	2101	3000	14	15 ottobre	15 aprile	4271
F	3001	+∞	nessuna limitazione (n.l.)	n.l.	n.l.	1071

Figure SM 1. a) Italian thermal zones identified to regulate the heating need. b) Periods and hours of heating activation, per thermal zone (elaborated from [8]).

To obtain the value of the average thermal energy requirement, the cubic meters of the dwelling have been multiplied for a specific thermal factor, function of location. It has been considered a fixed apartment height.

$$Average\ thermal\ requirement = Thermal\ Factor \cdot Volume \tag{SM 14}$$

Later, to find the daily thermal energy requirement (Equation (SM 15)), the value just obtained has been multiplied by the hours of heating activation, defined by GG.

$$Daily\ thermal\ requirement = Average\ thermal\ requirement \cdot hours \tag{SM 15}$$

Finally, to obtain the hourly variation of the thermal load demand (Equation (SM 16)), DispaSET-SideTools was adopted [9]. The DispaSET-SideTools is a side-project that prepares various types of input data to the DispaSET readable format with the main purpose of data analysis and processing.

The Dispa-SET model [10]–[12] is an open-source unit commitment, and optimal dispatch model focused on the balancing and flexibility problems in European grids. DispaSET-SideTools instead provides the share of Italian hourly heating usage. In this way, it has been possible to obtain the hourly variation of the daily thermal demand.

$$Daily\ \text{thermal}\ requirement = Average\ tThermal\ requirement \cdot hours \quad \text{(SM 16)}$$

After having obtained the hourly variation of the thermal demand in a day, so a daily heating demand, this has been repeated for all the days included in the activation period sanctioned by the DPR 412/93.

2.1.3 Cooling

The cooling demand was constructed with a method and assumptions very similar to those adopted for heating demand. Actually, no climatic zones exist as regards the cooling need. In the literature there are studies that report a variable cooling factor depending on the location though. Generally, that factor already considers the 6 hours of daily activation, without making distinction between cities [13]. In this work, the cooling activation period corresponds to the summer one. The daily requirement has been found by multiplying the cooling factor by the size of the space to be cooled.

$$Daily\ \text{cooling}\ requirement = Cooling\ factor\ \cdot Floor\ surface \quad \text{(SM 17)}$$

Then, to find the hourly variation of the cooling load demand (Equation (SM 18) as for heating, statistic data are used.

$$Hourly\ \text{cooling}\ \text{d}emand\ = Daily\ \text{cooling}\ requirement \cdot hourly\ share \quad \text{(SM 18)}$$

After having obtained the hourly variation of the cooling demand in a day, this has been repeated for all the days included in the activation period. Since there are no regulations, the activation period was supposed to be the summer-week for all the location analyzed.

2.1.4 Transport

The hourly variation for the transport demand was built from a random-function in MATLAB later adapted to the different drivers' behaviour according on statistical data. Different profiles demands have been created, each corresponding to different driver's behaviour:

- demand profiles designed on drivers who generally use the car for very short distances,
- demand profiles thought for drivers who, even just to reach the workplace for example, must travel longer daily distances,

- demand profiles designed for intermediate needs.

For the last two types of drivers, the demand profiles also include moments of long journeys which could represent pleasure or work trips.

2.1.5 Domestic hot water

The demand for DHW is based on the knowledge of water consumption. From the Italian National Statistic Office (ISTAT) data, it is possible to know the total daily personal DHW consumption in each city [14]. This has been the starting point for the calculation of DHW demand. Moreover, it must be considered that, during the year, a peak consumption may occur. To obtain the maximum values, percentage increases have been added on the average ISTAT value of water consumption, as follows:

- +30%, for the month of maximum consumption. The months of maximum consumption are the summer months given the greater need for personal cleaning since the increased transpiration;
- +20%, for the days of maximum consumption. These are generally the festive and pre-festive.

These increases are cumulative over the average value. In this way it was possible to obtain the daily water consumption, still expressed in l/day/pp. This one presents the increases shown earlier, in related day/period of the year.

To obtain the daily power required for the heating of the water consumption, a multiplication between the water flow rate q, the water heat capacity c_p, and the difference between aqueduct water temperature T_a and home water temperature T_h is needed.

$$Domestic\ daily\ hot\ water\ demand = q \cdot c_p \cdot (T_h - T_a) \quad \text{(SM 19)}$$

At the end, to find the hourly hot water demand, the DHW demand obtained in Equation (SM 19) was randomized in RAMP. Before proceeding for this step, it should be noted that the personal daily water consumption is usually divided as follows [15]:

- 60 l/day/pp for daily personal cleaning;
- 45 l/day/pp for hygienic;
- 50 l/day/pp for shower;
- 20 l/day/pp for dishes washing;
- 30 l/day/pp for laundry.

Basing on these values, the personal water consumption has been divided in three sub-categories:

- 24% shower;
- 51% personal cleaning and hygiene;
- 25% dishes washing and laundry.

This has been done because RAMP allows to consider the number of times in a day or a week in which an appliance could be used. Thanks to this opportunity, it was possible to differentiate the weekly usage of the dish washer or washing machine from the daily water usage for personal hygiene.

At the end, each sub-category has been randomized and then summed to the other in order to achieve again the 100% of the total hot water demand.

2.1.6 Cooking

Italy is more fossil-based than European Union in cooking sector. In fact, according to Eurostat [16], there is a large difference between EU and Italy especially regards the use of electricity for cooking: it is equal to about 50% for the EU and only 16% for Italy. Instead, the reverse happens for the use of natural gas for cooking, equal to 31% for the EU and more than double for Italy. The Italian government, in the National Energy Strategy (SEN) of 2017 [17], planned to implement a process of gradual replacement of fossil fuels with renewable sources. The expected trend is therefore to reduce as much as possible fossil sources and so, the implicit attempt is to orient, where it is possible, towards electricity-based technologies. For what concerns the cooking demand, there should be the need of a technological switch, from the gas stove to induction one. It should be also noted that the induction stove has twice the efficiency of the gas stove [18].

RAMP has been used also for the calculation of the cooking demand. In this way it was possible to randomize different combinations of breakfast-lunch-dinner typologies [19]. Each meal of the Italian diet has been characterized through parameters already seen for the construction of the electricity demand (e.g. the required power developed by the stove, cooking duration, minimum cooking time…). For the cooking demand also other parameters has been considered:

- the stove thermal power variation;
- the number of behavioural preferences randomizations;
- the presence of specific cycles in which more power levels are maintained for a specific period.

The last point simply describes the level of power to cook a specific plate: a piece of meat could be cooked for the initial few minutes at high power and for the last minutes at low power.

2.2. Techno-economic data

Each technology, considered within the reference energy system described in Section 3.2. of the main manuscript, has been characterized by economic and environmental parameters. In particular regarding economic data, the specific investment cost (expressed per minimum unit of capacity installed) and the specific operation cost (expressed per unit of energy produced) were needed, while each technology has been characterized also by emission factors: the specific carbon emissions embedded (expressed per minimum unit of capacity installed) and the specific direct carbon emissions (expressed per unit of energy produced). The following tables resumes such information.

*Table SM 1. Economic input parameters characterizing each technology included in the reference energy system. ** The electricity price coming from the national grid is one of the sensitivity parameters, therefore it is variable among 0.15 and 0.45€/kWh.*

Technology	Minimum capacity unit	Energy production unit	Specific investment cost [€/minimum capacity unit]	Specific operation cost [€/production unit]	References
National grid	3 kW	kWh_e	0	**	[20]
Photovoltaic panels	1 kW	kWh_e	2500	0	[21]
Home battery system	7 kW	kWh_e	8000	0	[22]
ICEV	1 car	km	17000	0.11	[23], [24]
BEV	1 car	km	27300	0	[25]
Gas boiler	24 kW	kWh_{th}	1000	0.11	[26]
Heat pump	4 kW	kWh_{th}	1000	0	[27]
Solar thermal panel	1 kW	kWh_{th}	1300	0	[28]
Gas Stove	6 kW	kWh_{th}	250	0.25	[29]
Induction stove	6 kW	kWh_e	400	0	[30]
Thermal insulation	m^2	- kWh_{th}	12852	0	[31]

Table SM 2. Environmental input parameters characterizing each technology included in the reference energy system

Technology	Minimum capacity unit	Energy production unit	Specific carbon footprint [kgCO2eq/ minimum capacity unit]	Specific direct carbon emissions [kgCO2eq/ production unit]	References
National grid	3 kW	kWh_e	0	0.30	[32]
Photovoltaic panels	1 kW	kWh_e	80	0	[33], [34]
Home battery system	7 kW	kWh_e	615	0	[35]
ICEV	1 car	km	8000	0.15	[36], [37]
BEV	1 car	km	8350	0	[36], [37]
Gas boiler	24 kW	kWh_{th}	130	0.26	[38], [39]
Heat pump	4 kW	kWh_{th}	30	0	[40]
Solar thermal panel	1 kW	kWh_{th}	300	0	[41], [42]
Gas stove	6 kW	kWh_{th}	62	0.31	[43]–[45]
Induction stove	6 kW	kWh_e	97	0	[43], [46]
Thermal insulation	m^2	- kWh_{th}	514	0	[47], [48]

Regarding, in the end, the discount rate r, it was decided to use the 10 years yield of Italian government bonds, which at the moment of writing is around 4%.

3. Results: complementary information

This section provides additional outcomes which complement the result analysis performed in the main manuscript (Section 4). In particular, it is interesting to try visualizing the second-order implications on BEV preferability, obtainable investigating those clusters of solutions in which tuples of sensitivity parameters values can be matched together. In particular, the following Figures provide heatmaps showing the number of solutions in which BEV is preferred when two sensitivity parameters assume respectively the value on the rows and on the columns of each table.

		Annual travelled distance [km]			
		5000	10000	20000	25000
Ownership time [years]	3	0	0	18	117
	5	0	0	390	778
	7	0	91	1096	1354
	10	0	623	1541	1575
Grid electricity price [€/kWh]	0.45	0	102	395	473
	0.4	0	104	396	479
	0.35	0	102	400	504
	0.3	0	102	421	527
	0.25	0	100	431	572
	0.2	0	96	489	612
	0.15	0	108	513	657
Gasoline price [€/litre]	1.4	0	0	352	497
	1.6	0	63	496	652
	1.8	0	126	618	793
	2	0	216	744	895
	2.2	0	309	835	987
BEV incentives [€]	1000	0	0	409	582
	2000	0	57	509	666
	3000	0	125	596	746
	4000	0	189	711	870
	5000	0	343	820	960

		Annual travelled distance [km]			
		5000	10000	20000	25000
PV capacity [kW]	0	0	18	405	698
	1	0	66	348	478
	2	0	37	220	276
	3	0	171	178	226
	4	0	272	120	136
	5	0	70	738	179
	6	0	30	716	1055
	7	0	10	123	476
	8	0	10	50	150
	9	0	0	24	25
	10	0	0	41	21
	11	0	10	7	29
	12	0	0	0	0
	13	0	10	25	25
	14	0	0	0	0
	15	0	10	25	25
	16	0	0	0	0
	17	0	0	0	0
	18	0	0	25	25

Figure SM 2. Influence of the variation of "annual travelled distance" parameter on BEV preferability, matched with the variation of each other sensitivity parameter. BEV preferability is proxied by the color scale of the heatmaps. The values contained in each cell refer to the number of solutions where BEV is preferred in the conditions determined by matching row-column information.

		Ownership time [years] 3	5	7	10
Annual travelled distance [km]	5000	0	0	0	0
	10000	0	0	91	623
	20000	18	390	1096	1541
	25000	117	778	1354	1575
Grid electricity price [€/kWh]	0.45	0	100	336	534
	0.4	0	104	342	533
	0.35	9	121	342	534
	0.3	9	159	347	535
	0.25	27	180	362	534
	0.2	36	243	389	529
	0.15	54	261	423	540
Gasoline price [€/litre]	1.4	0	27	226	596
	1.6	0	97	421	693
	1.8	9	219	553	756
	2	36	353	648	818
	2.2	90	472	693	876
BEV incentives [€]	1000	0	57	335	599
	2000	0	126	422	684
	3000	0	212	500	755
	4000	36	337	578	819
	5000	99	436	706	882

		Ownership time [years] 3	5	7	10
PV capacity [kW]	0	134	564	423	0
	1	1	273	258	360
	2	0	69	287	177
	3	0	71	218	286
	4	0	47	136	345
	5	0	107	414	466
	6	0	37	679	1085
	7	0	0	126	483
	8	0	0	0	210
	9	0	0	0	49
	10	0	0	0	62
	11	0	0	0	46
	12	0	0	0	0
	13	0	0	0	60
	14	0	0	0	0
	15	0	0	0	60
	16	0	0	0	0
	17	0	0	0	0
	18	0	0	0	50

Figure SM 3. Influence of the variation of "ownership time" parameter on BEV preferability, matched with the variation of each other sensitivity parameter. BEV preferability is proxied by the color scale of the heatmaps. The values contained in each cell refer to the number of solutions where BEV is preferred in the conditions determined by matching row-column information.

		Grid electricity price [€/kWh] 0.45	0.4	0.35	0.3	0.25	0.2	0.15
Annual travelled distance [km]	5000	0	0	0	0	0	0	0
	10000	102	104	102	102	100	96	108
	20000	395	396	400	421	431	489	513
	25000	473	479	504	527	572	612	657
Ownership time [years]	3	0	0	9	9	27	36	54
	5	100	104	121	159	180	243	261
	7	336	342	342	347	362	389	423
	10	534	533	534	535	534	529	540
Gasoline price [€/litre]	1.4	107	107	108	111	116	138	162
	1.6	152	152	155	162	176	198	216
	1.8	195	198	204	211	225	243	261
	2	239	242	247	260	272	289	306
	2.2	277	280	292	306	314	329	333
BEV incentives [€]	1000	128	127	129	139	141	156	171
	2000	155	159	161	168	179	194	216
	3000	188	190	197	203	213	233	243
	4000	226	227	235	244	262	279	297
	5000	273	276	284	296	308	335	351

		Grid electricity price [€/kWh] 0.45	0.4	0.35	0.3	0.25	0.2	0.15
PV capacity [kW]	0	0	0	8	9	87	279	738
	1	0	0	49	105	120	258	360
	2	0	9	24	36	156	188	120
	3	13	45	33	125	153	146	60
	4	39	51	87	124	100	127	0
	5	152	172	176	222	165	100	0
	6	325	368	408	329	272	99	0
	7	162	151	146	100	50	0	0
	8	110	50	50	0	0	0	0
	9	0	24	25	0	0	0	0
	10	24	38	0	0	0	0	0
	11	35	11	0	0	0	0	0
	12	0	0	0	0	0	0	0
	13	50	10	0	0	0	0	0
	14	0	0	0	0	0	0	0
	15	10	50	0	0	0	0	0
	16	0	0	0	0	0	0	0
	17	0	0	0	0	0	0	0
	18	50	0	0	0	0	0	0

Figure SM 4. Influence of the variation of "grid electricity price" parameter on BEV preferability, matched with the variation of each other sensitivity parameter. BEV preferability is proxied by the color scale of the heatmaps. The values contained in each cell refer to the number of solutions where BEV is preferred in the conditions determined by matching row-column information.

Parameter	Value	Gasoline price [€/litre] 1.4	1.6	1.8	2	2.2
Annual travelled distance [km]	5000	0	0	0	0	0
	10000	0	63	126	216	309
	20000	352	496	618	744	835
	25000	497	652	793	895	987
Ownership time [years]	3	0	0	9	36	90
	5	27	97	219	353	472
	7	226	421	553	648	693
	10	596	693	756	818	876
Grid electricity price [€/kWh]	0.45	107	152	195	239	277
	0.4	107	152	198	242	280
	0.35	108	155	204	247	292
	0.3	111	162	211	260	306
	0.25	116	176	225	272	314
	0.2	138	198	243	289	329
	0.15	162	216	261	306	333
BEV incentives [€]	1000	95	151	194	260	291
	2000	132	180	251	285	384
	3000	155	228	279	384	421
	4000	212	276	384	430	468
	5000	255	376	429	496	567

Parameter	Value	Gasoline price [€/litre] 1.4	1.6	1.8	2	2.2
PV capacity [kW]	0	81	150	219	297	374
	1	90	132	176	223	271
	2	56	83	110	133	151
	3	42	75	110	157	191
	4	26	64	101	144	193
	5	101	153	202	250	281
	6	250	331	384	411	425
	7	106	119	127	128	129
	8	40	41	42	43	44
	9	9	10	10	10	10
	10	9	15	15	12	11
	11	9	6	7	11	13
	12	0	0	0	0	0
	13	10	11	12	13	14
	14	0	0	0	0	0
	15	10	11	12	13	14
	16	0	0	0	0	0
	17	0	0	0	0	0
	18	10	10	10	10	10

Figure SM 5. Influence of the variation of "gasoline price" parameter on BEV preferability, matched with the variation of each other sensitivity parameter. BEV preferability is proxied by the color scale of the heatmaps. The values contained in each cell refer to the number of solutions where BEV is preferred in the conditions determined by matching row-column information.

Parameter	Value	BEV incentives [€] 1000	2000	3000	4000	5000
Annual travelled distance [km]	5000	0	0	0	0	0
	10000	0	57	125	189	343
	20000	409	509	596	711	820
	25000	582	666	746	870	960
Ownership time [years]	3	0	0	0	36	99
	5	57	126	212	337	436
	7	335	422	500	578	706
	10	599	684	755	819	882
Grid electricity price [€/kWh]	0.45	128	155	188	226	273
	0.4	127	159	190	227	276
	0.35	129	161	197	235	284
	0.3	139	168	203	244	296
	0.25	141	179	213	262	308
	0.2	156	194	233	279	335
	0.15	171	216	243	297	351
Gasoline price [€/litre]	1.4	95	132	155	212	255
	1.6	151	180	228	276	376
	1.8	194	251	279	384	429
	2	260	285	384	430	496
	2.2	291	384	421	468	567

Parameter	Value	BEV incentives [€] 1000	2000	3000	4000	5000
PV capacity [kW]	0	102	159	192	279	389
	1	108	133	176	220	255
	2	69	87	101	126	150
	3	53	78	105	139	200
	4	34	61	99	137	197
	5	125	161	199	234	268
	6	291	331	365	395	419
	7	112	118	122	128	129
	8	40	41	42	43	44
	9	9	10	10	10	10
	10	10	13	14	12	13
	11	8	8	8	11	11
	12	0	0	0	0	0
	13	10	11	12	13	14
	14	0	0	0	0	0
	15	10	11	12	13	14
	16	0	0	0	0	0
	17	0	0	0	0	0
	18	10	10	10	10	10

Figure SM 6. Influence of the variation of "BEV incentives" parameter on BEV preferability, matched with the variation of each other sensitivity parameter. BEV preferability is proxied by the color scale of the heatmaps. The values contained in each cell refer to the number of solutions where BEV is preferred in the conditions determined by matching row-column information.

		PV capacity [kW]																		
		0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
Annual travelled distance [km]	*5000*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10000	18	66	37	171	272	70	30	10	10	0	0	10	0	10	0	10	0	0	0
	20000	405	348	220	178	120	738	716	123	50	24	41	7	0	25	0	25	0	0	25
	25000	698	478	276	226	136	179	1055	476	150	25	21	29	0	25	0	25	0	0	25
Ownership time [years]	*3*	134	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	564	273	69	71	47	107	37	0	0	0	0	0	0	0	0	0	0	0	0
	7	423	258	287	218	136	414	679	126	0	0	0	0	0	0	0	0	0	0	0
	10	0	360	177	286	345	466	1085	483	210	49	62	46	0	60	0	60	0	0	50
Grid electricity price [€/kWh]	*0.45*	0	0	0	13	39	152	325	162	110	0	24	35	0	50	0	10	0	0	50
	0.4	0	0	9	45	51	172	368	151	50	24	38	11	0	10	0	50	0	0	0
	0.35	8	49	24	33	87	176	408	146	50	25	0	0	0	0	0	0	0	0	0
	0.3	9	105	36	125	124	222	329	100	0	0	0	0	0	0	0	0	0	0	0
	0.25	87	120	156	153	100	165	272	50	0	0	0	0	0	0	0	0	0	0	0
	0.2	279	258	188	146	127	100	99	0	0	0	0	0	0	0	0	0	0	0	0
	0.15	738	360	120	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gasoline price [€/litre]	*1.4*	81	90	56	42	26	101	250	106	40	9	9	9	0	10	0	10	0	0	10
	1.6	150	132	83	75	64	153	331	119	41	10	15	6	0	11	0	11	0	0	10
	1.8	219	176	110	110	101	202	384	127	42	10	15	7	0	12	0	12	0	0	10
	2	297	223	133	157	144	250	411	128	43	10	12	11	0	13	0	13	0	0	10
	2.2	374	271	151	191	193	281	425	129	44	10	11	13	0	14	0	14	0	0	10
BEV incentives [€]	*1000*	102	108	69	53	34	125	291	112	40	9	10	8	0	10	0	10	0	0	10
	2000	159	133	87	78	61	161	331	118	41	10	13	8	0	11	0	11	0	0	10
	3000	192	176	101	105	99	199	365	122	42	10	14	8	0	12	0	12	0	0	10
	4000	279	220	126	139	137	234	395	128	43	10	12	11	0	13	0	13	0	0	10
	5000	389	255	150	200	197	268	419	129	44	10	13	11	0	14	0	14	0	0	10

Figure SM 7. Influence of the variation of "PV capacity" parameter on BEV preferability, matched with the variation of each other sensitivity parameter. BEV preferability is proxied by the color scale of the heatmaps. The values contained in each cell refer to the number of solutions where BEV is preferred in the conditions determined by matching row-column information.

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