Climate and cultural based design and market valuable technology solutions for Plus Energy Houses

Guidelines to assess the co-benefits of Plus Energy Buildings

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Authors:

Francesco Bosello, University Ca' Foscari of Venice, CMCC Foundation and RFF-CMCC EIEE
Andrea Bigano, CMCC Foundation and RFF-CMCC EIEE
Aisling Sealy Phelan, CMCC and University of Padua
Anna Alberini, University of Maryland and CMCC
Valentina Giannini, CMCC Foundation and RFF-CMCC EIEE

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Acronyms

ADPE	Abiotic depletion potential for non-fossil resources
ADPF	Abiotic depletion potential for fossil resources
APA	Acidification potential
CRU	Components for re-use
DCE	Discrete Choice Experiment
EEE	Exported electrical energy
EET	Exported thermal energy
EP	Eutrophication potential
FW	Use of net fresh water
GWP	Global warming potential
HWD	Hazardous waste disposed
MER	Material for Energy Recovery
MFR	Materials for recycling
NHWD	Non-hazardous waste dispose
NRSF	Use of non-renewable secondary fuels
ODP	Depletion potential of the stratospheric ozone layer
PED	Positive Energy District
PENRE	Non-renewable primary energy as energy carrier
PENRM	Non-renewable primary energy as material utilization
PENRT	Total use of non-renewable primary energy resource
PERE	Renewable primary energy as energy carrier
PERM	Primary energy resources used as raw materials
PERT	Total use of renewable primary energy resources
POCP	Formation potential of tropospheric ozone photochemical oxidants
RSF	Use of renewable secondary fuels
RWD	Radioactive waste disposed
SM	Input of secondary material
WTA	Willingness to accept
WTP	Willingness to pay

Executive summary

This report summarizes the processes and results of an activity estimating the co-benefits associated with Plus Energy Buildings (PEBs) at household and community level and aims to provide guidelines to any interested parties who wish to carry out a similar activity in the future. These guidelines can be used by a variety of different stakeholders, such as real estate agents, building occupants, policy makers and technology developers to estimate and integrate the co-benefits associated with PEBs into business models and cost assessments, and can be presented within marketing strategies aimed at promoting the use and share of PEBs in the future. Moreover, the guidelines and estimation of co-benefits aim to demonstrate the importance of the additional benefits for both households and wider society that can originate from PEBs. This will highlight to policy makers the importance of supporting PEBs with adequate policies, so as to increase their future share, to move past the current norm of the nearly Zero Energy Buildings (nZEB)and to harness the potential gains.

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) describes co-benefits as “the positive effects that a policy or measure aimed at one objective might have on other objectives, without yet evaluating the net effect on overall social welfare” (AR5, 2014). In other words, co-benefits can be thought of as the additional positive effects brought by a policy measure, that occur regardless of and in addition to the originally predetermined policy goals. In the context of PEBs, these can be considered as any *additional benefits* over and above the energy savings, and therefore, as here called, non-energy co-benefits.

The co-benefits potentially originated by PEBs can be usually attributed to a “use”. Accordingly, they can be evaluated by quantifying a “use value”. This, however, can encompass both material and immaterial aspects. The first, can be, for instance, a lower quantity of pollutants in the atmosphere, the second, is the sense of satisfaction originating by living in a more “environmental-friendly” house. In both cases, observable market transactions and official “prices” that can provide support to evaluation may not always be evident. Accounting for these complexities, the present study proposes two different assessment methods: a direct costing approach and a stated preferences approach.

With the first method, we associate, when possible, a straight monetary value to a clearly quantifiable source (i.e. a performance indicator) of co-benefits. With the second method, we elicit through interviews the preferences, expressed as monetary value assessments of the co-aa clear benefits in a hypothetical setting, of a representative

sample of potential users. By asking directly to people, this method allows an evaluation of co-benefits also when "markets" and "prices" are not available.

The co-benefits eventually selected for the direct costing evaluation are the following:

At the household level: Reduction of construction material and demolition waste and lower operational and maintenance costs.

At the community level: Mitigation of climate change, employment creation, improvement in social welfare (reduction in energy poverty), reduction in air pollution (reduction in emissions of particulate matter), reduced ozone depletion and tropospheric ozone photochemical oxidants, reduction in acidification potential, reduction in eutrophication potential, reduction in abiotic depletion potential for fossil and non-fossil resources and reduced water use.

The two approaches will cover two complementary sets of co-benefits. Direct costing can cover only the co-benefits for which a clear "price tag" can be identified in the market. For the more immaterial co-benefits, we apply a for the stated preferences evaluation approach to the following final selection:

- Energy Balance: and the role of energy in the building, with a special focus on energy security,
- Indoor Environmental Quality: the (highly subjective) perception of thermal comfort, and air quality,
- Adaptability: the ability of the building to adapt to user needs

In our stated preference study, we explore how much homeowners value co-benefits of energy efficient and positive-energy dwellings, (particularly the co-benefits enhancing energy security), and we test whether investment in them can be made more attractive by boasting about the fact that it will raise the value of the property or its rental income potential. Besides energy security we also explore other co-benefits of energy efficient and positive-energy dwellings among those selected within Cultural-E, namely the improvement in air quality associated with filtration and mechanical ventilation systems typical of zero-energy or positive-energy homes, and the potential of energy optimization systems based on sensors and software dedicated to the electric appliances in the home and to space heating and cooling.

We found that for the most part, respondents were willing and able to answer the rental value questions, even though about one third of the respondents said that the change in rental value was zero for each of the seven hypothetical scenarios they faced. When these "always zero" respondents are excluded, the remainder values connection to a positive energy district some €39/month, centralized air filtration and centralized ventilation about €41/month each, and energy optimization sensors and software €51 (for appliances) and €38 (for space heating and cooling).

The respondents' valuations appear to be internally valid, in that additional questions about participation in a Positive Energy District (PED) reveal a mean WTP and a mean WTA for PED participation that bracket the effect of a PED connection on rental values.

1. Introduction

This report summarizes the processes and results of an activity estimating the co-benefits associated with Plus Energy Buildings (PEBs) at household and community level, and aims to provide guidelines to any interested parties who wish to carry out a similar activity in the future.

In the buildings sector, it is now widely recognised that actions improving energy efficiency that are well planned and effectively implemented can significantly contribute towards achieving a wide range of other environmental, economic, and social goals (Shnapp et al., 2020).

The IPCC AR6 (2022) has categorised the multiple benefits of mitigation measures in the building sector in the following way:

- Positive health impacts resulting from improved indoor conditions, alleviation of energy poverty, improved ambient air quality and reduction of the heat island effect.
- Environmental benefits, for example, reduced local air pollution, lower stress on ecosystems (reduced acidification, eutrophication etc.), and infrastructures.
- Better resource. e.g., water and energy, management.
- Positive impacts on social well-being, decreased energy expenditures leading to changes in disposable income, distributional effects of policies, fuel poverty alleviation, and rebound effects.
- Positive micro and macro-economic effects, for instance, labour productivity gains, increased asset values for energy efficient buildings, creation of new jobs, decreased employment in the fossil fuel sector etc.
- Positive implications for energy security, increased access to modern energy resources, decreased dependence on energy imports etc.

It is evident that mitigation measures in the building sector can have impacts over and above reducing climate change and energy savings (Sharmina et al., 2009). Furthermore, evidence suggests that the value of these impacts, often referred to interchangeably as co-benefits, non-energy benefits or multiple benefits, is substantial and it could be equal to or even greater than the value of the direct energy savings of these policies (Kats, 2006; Sharmina et al., 2009; IPCC; 2022).

The Fifth Assessment Report (AR5) of the IPCC describes co-benefits as “the positive effects that a policy or measure aimed at one objective might have on other objectives, without yet evaluating the net effect on overall social welfare" (AR5, 2014). In other words, co-benefits can be understood as the additional positive effects brought by a policy measure that occur regardless of and in addition to the predetermined goals of the policy. In the context of positive energy houses, these can be thought of as any *additional benefits* over and above the energy savings.

The Cultural-E project aims, among other, to highlight the minor extra costs associated with PEBs when compared to the current norm (2021) of nearly Zero Energy Buildings (nZEB) (EPBD, 2018; CRAVEzero D6.4, 2020). In this process, co-benefits play a key role that needs to be considered. Nonetheless, in practice, often these benefits are excluded or underestimated due to the associated difficulties in their identification and calculation (CRAVEzero D6.4, 2020 Sharmina et al., 2009). Quantifying, and where possible, monetizing the co-benefits of mitigation policies is an important endeavour and can allow for their inclusion in cost-benefit analysis and help support the adoption of ambitious emissions reduction targets (IPCC, 2022). This report delineates the methodology followed by Cultural-E to develop the co-benefit assessment.

An ideal evaluation process consists of four phases (Figure 1.1):

1. the identification of the potential co-benefits,
2. the choice of indicators that substantiate the benefits,
3. the choice of a method/metric to associate the indicators with a value,
4. valuation.

Probably the biggest challenge in the process relates to the monetisation of co-benefits when, as it often occurs, they are partially if not totally "outside" official market transactions. The importance of having market transactions as supporting reference resides in the possibility to observe price formations. While being aware of the many circumstances in which prices are not correct indicators of values (market "failures" are indeed at the basis of public sector, welfare and environmental economics (Pearce et al. 1994) they are nonetheless a starting point for the valuation. However, even when the co-benefits can be associated with a concrete use of a good or service, finding observable and useful market transactions can be difficult. Think, for instance, of the difficulty to "price through markets", a reduced risk of mortality, morbidity or the "sense of satisfaction" of living in an environmentally friendly house. Identifying market transactions becomes almost impossible when the co-benefit is associated with a non-use value, that is, when it can originate "welfare" changes independently upon any possible present or future use of a good or a service.

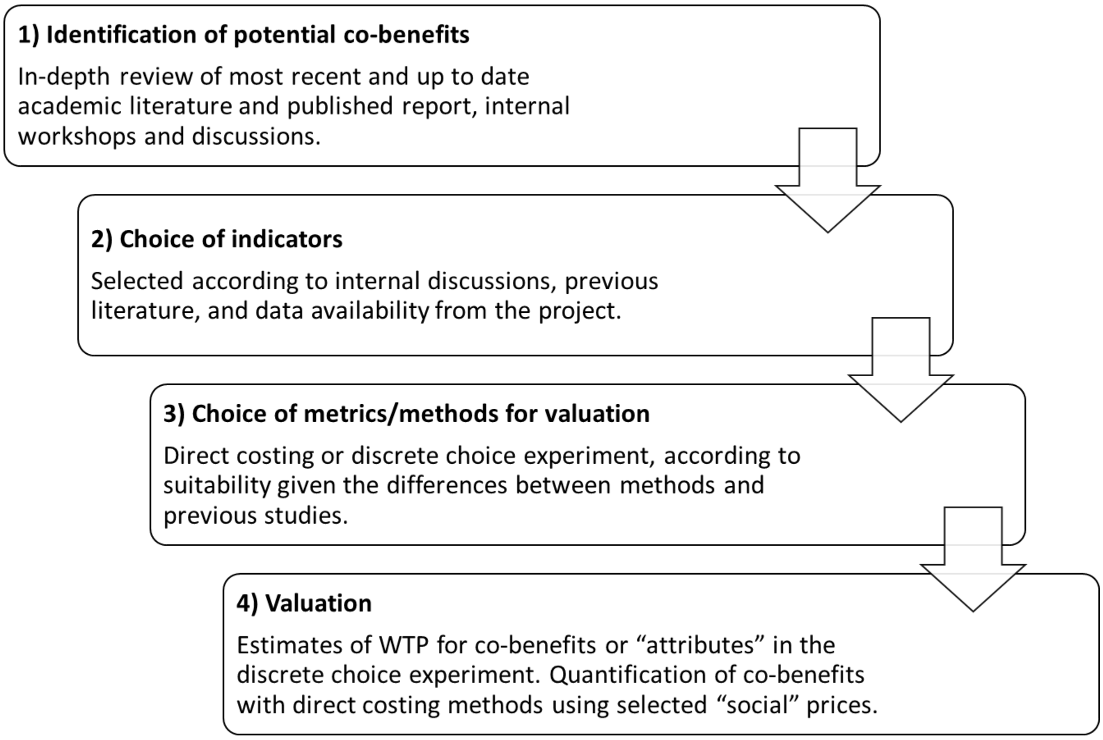


Figure 1.1: Schematic of ideal evaluation process of co-benefits

The co-benefits potentially originated by PEBs can be usually attributed to a "use". Accordingly, they can be evaluated by quantifying a "use value". This however can encompass both material and immaterial aspects, and, as said, market transactions are not always evident. Accounting for these complexities, the present study proposes two different assessment methods: a direct costing approach and discrete choice experiment approach.

With the first method, we associate a straight monetary value to a clearly quantifiable source (i.e., a performance indicator) of co-benefits. To make a practical example: the value of the climate stabilization co-benefit that can be originated by a Plus Energy Building is quantified by taking the avoided tons of green-house gas (GHG) emissions (an environmental performance indicator, also called Global Warming Potential - GWP) that can be originated and multiplying by the social cost of carbon. The social cost of carbon is a translation in monetary terms (Euros or Dollars) of the stream of damages a unit (ton) of emitted carbon dioxide equivalent (CO_2 eq.) originates along its permanence into the atmosphere (Renner and Kingdon 2019). Since the Cultural-E project aims to go beyond the current nZEB standard, avoided GHG emissions can be quantified in a relative way, i.e., the PEB's environmental performance (in terms of lifecycle GHG emissions) is afterwards compared against a “reference building”, which is a reference nZEB.(See also the appendix for an example applied to the evaluation of warming/cooling/insulating technologies the Cultural-E project has identified).

Unit monetary values for the different potential co-benefits can be extracted or inferred from the literature and applied in a similar way (see below section 4). Nonetheless, this “pricing” method can only partially capture aspects like changes in health status, in air quality, or in other environmental, ecosystem, biodiversity quality, which, as said, are also linked to a non-market dimension. Accordingly, a complementary approach is also proposed: the use of a stated preference approach. Briefly, the methodology consists in eliciting through interviews the preferences, expressed in terms of willingness to pay for the different attributes of a PEB, of a representative sample of potential users. By asking directly to people, this method allows an evaluation of co-benefits also when “markets” and “prices” are not of support.

In what follows section 3 describes the co-benefit identification and selection procedure, section 4 reports the evaluation methods detailing how each potential co-benefit can be defined and evaluated, section 5 provides remarks and conclusion. In the appendixes we provide a practical example of the application of the direct costing methodology to the assessment of the GWP embedded in the heating/cooling/insulating technologies aimed for PEBs, and the detailed development history of the stated preferences questionnaire together with the full list of questions.

2. Co-benefit identification and selection

Non-energy benefits of PEBs can be plenty. It is thus helpful to identify and classify the different co-benefits before moving onto a more in-depth assessment (Sharmina et al., 2009). Co-benefits can influence at the household level, for example, by increasing user comfort from improved indoor environmental quality, or at a more macro or community level, for example, by mitigating climate change (Almeida, et al., 2017).

An initial set of co-benefits has been identified within the scope of Cultural-E by means of an in-depth literature review of the latest scientific publications and internal workshops. The co-benefits were classified according to the scale - household or community level - and then distinguished among environmental, user wellbeing, economic, and social impacts (Table 2. 1).

Household level		Community	
Direct effects	Co-impacts	Direct effects	Co-impacts
Reduction of energy consumptions	Thermal comfort	Reduction of CO_2 emissions	Incentives for the construction sector --> more private investment
Reduction of energy consumption costs	Acoustic comfort	Reduction of energy consumption	Lower energy costs
Building life-cycle cost reduction	Visual comfort	Reduction of dependence on fossil fuels --> reduction of import costs and greater country tax stability	New business opportunities
	IAQ indoor air quality		Mitigation of climate change
	Building Physics		Reduction of atmospheric pollution
	Health improvement		Reduction of construction / demolition waste
	Easy of use		Biodiversity protection
	Safety		Environmental resource protection
	Aesthetics of the building		Reduction of water consumption and waste water production
	Improvement of health conditions / Reduction of work leave (smart working)		Conservation of ecosystems
	Reduction of psychological effects		Improvement of social welfare
	Resilience to climate change		Aesthetics of the building - neighborhood enhancement
	Increase in productivity (smart working)		Mortality / morbidity reduction
	Lower cost of energy		Urban heat island mitigation
	Less need for energy subsidies		Reduction of outdoor air pollution
	Easier to sell / rent at higher real estate prices		Energy security
	Lower maintenance costs		
	Increase in the value of the building		
ENVIRONMENTAL	USER WELL-BEING	ECONOMIC	SOCIAL

Table 2. 1 Typology of co-benefits of PEBs.

From this initial list, a selection has been made of the co-benefits that could be evaluated in practice by the two methods, direct costing and stated preferences. The co-benefits were selected based on the availability of estimated social costs or market prices for use in direct costing, leaving a subset of co-benefits to which there were no associated prices available for use. This subset of co-benefits for which no prices are available can in theory be estimated by a stated preferences approach, subject to the constraint that these methods only estimate a value for a limited number of co-benefits (or attributes), to avoid overburdening respondents, and hence this subset was further refined to a suitable number according to their relevance. The process is described in detail in section 3.2.2.

The selection of co-benefits to be evaluated through direct costing is being conducted following a stepwise procedure. Firstly, an overall external evaluation of feasible co-benefits for direct costing was undertaken without considering the specifics of the Cultural-E project. Next, a review of the most recent and up-to-date academic literature and published reports applying a “direct costing” approach to evaluate the multiple benefits of energy efficiency measures was performed. Then, the co-benefits in Table 1 have been ranked according to their ease of quantifiability using the methods identified in the literature review (see Table 2. 2). Ease of quantifiability took into account data availability, level of complexity and robustness of methods, time requirements, levels of uncertainty, assumptions necessary for the methods. Finally, an internal evaluation of co-benefits considering data availability from the Cultural-E project was performed.

Quantifiability	Scale of benefit			
	Household level	Comment	Community level	Comment
High	Lower maintenance costs	Explicit market prices for maintenance services, exist and therefore direct monetization is possible.	Mitigation of climate change	Metrics like the Social Cost of Carbon that are readily available and can be used to value a reduction in the quantity of greenhouse gas emissions and the resulting climate mitigation.
	Improvement of health conditions / Reduction of work leave (smart working)	Direct costing studies exist, however, there is a lack of standard metric to quantify changes in productivity resulting from the improved energy efficiency actions. Still, some studies are available that estimated a reduction in sick leave from improved IEQ, and values this impact based on the GVA of "office workers". This method has some weakness for a direct application to Cultural-E as buildings are not specifically used by office workers.	Reduction of atmospheric pollution	Studies reporting the social costs of pollutants are available as well as studies connecting emissions of pollutants with human health impacts.
	Increase in productivity (smart working)	Overlap with co-benefit of reduced work leave from improved health conditions.	Reduction of water consumption and wastewater production	Can be valued using the market cost of water treatment services. It is thus suitable for a direct monetary evaluation due to the associated market prices.
	Increase in the value of the building	Overlap with higher rental or sale prices. Same justification.	Reduction of outdoor air pollution	Overlap with atmospheric pollution co-benefit but can be assessed in the same manner.
	Easier to sell / rent at higher real estate prices	Two alternative methods can be used: a benefit transfer from previous hedonic pricing studies estimating the price premium for energy efficient buildings as per Bleyl et al., 2018. Or estimate the price premium based on the value of energy savings that building owners will benefit from as per Reuter et al., 2020.	Reduction of construction / demolition waste	Can be valued easily due to the availability of market prices for waste treatment services. The economic value of reduced waste materials and or materials for recycling can be estimated using the corresponding market price for the service used (EC, 2014).
			Improvement of social welfare	In principle the effect of energy efficiency can be translated into improved social welfare assessing the impact on the expenditure of low-income households. Low data requirements.
	Health improvement	Overlap with health impacts of reduced air pollution. Other health improvements such as psychological or stemming from better Indoor Environmental Quality do not have market prices associated and are not suitable for direct costing. There exists a mortality cost of carbon (MCC), that estimates the number of deaths caused by the emissions of one additional metric ton of carbon dioxide, however, valuing this co benefit could risk double counting.	Energy security	Indicators used: “value of lost load” or VoLL. VoLL is a monetary expression for the costs associated with inter- or disruptions of electricity supply, as a result of production, transmission or distribution failures. High uncertainty and assumptions necessary.

Medium			Mortality / morbidityreduction	Overlap with health benefits from reduced air pollution.
	Resilience to climate change	It is difficult to value the additional resilience of building to climate change impacts, storms, flooding etc. as the literature features some lack of indicators and of monetisation techniques. In theory this benefit could be valued using the cost of avoided repairs.	Less need for energy subsidies	Direct costing studies exist, but many assumptions and projections on future prices and subsidies are needed.
	Safety	Lack of example direct costing studies and/or market or social prices.	Incentives for the construction sector --> more private investment	Difficult to evaluate, based on assumptions of future market conditions, lack of studies.
Low	Lower cost of energy	Difficult to evaluate, involves complex projections and assumptions on future energy prices	Urban heat island mitigation	High data requirements, e.g. total heat stress reduction, demographic data to Identify the number of people that will benefit, specifically those who are vulnerable to heat stress. Also requires information on the treatment costs of heat-related illnesses.
	Thermal comfort	Lack of example direct costing studies and/or market or social prices.	New business opportunities	Inherently difficult to estimate, based on assumptions with no available benchmarks.
	Acoustic comfort	Lack of example direct costing studies and/or market or social prices.	Biodiversity protection	Lack of example direct costing studies and/or market or social prices.
	Visual comfort	Lack of example direct costing studies and/or market or social prices.	Aesthetics of the building - neighbourhood enhancement	Difficult to evaluate, aesthetics of a building is highly subjective, lack of prices and metrics to assess.
	IAQ indoor air quality	Lack of example direct costing studies and/or market or social prices.	Conservation of ecosystems	Lack of example direct costing studies and/or market or social prices.
	Building Physics	Lack of example direct costing studies and/or market or social prices.	Environmental resource protection	Lack of example direct costing studies and/or market or social prices.
	Ease of use	Lack of example direct costing studies and/or market or social prices.		
	Reduction of psychological effects	Learning and productivity benefits are already a co-benefit addressed. Lack of studies linking energy efficient buildings with a reduction in psychological effects		

Table 2. 2. Co-benefits: ease of quantification and comments

The evaluation of several co-benefits proved to be a challenging task: the calculations would have involved unacceptably high levels of uncertainty (i.e., too many subjective/uncontrollable assumptions) and/or unfeasible data requirements. They were hence excluded from the direct costing assessment. However, it is important to note that these excluded co-benefits are also important and may have significant values.

The co-benefits eventually selected for the direct cost evaluation are the following:

At the household level: Reduction of construction material and demolition waste and lower operational and maintenance costs.

At the community level: Mitigation of climate change, employment creation, improvement in social welfare (reduction in energy poverty), reduction in air pollution (reduction in emissions of particulate matter), reduced ozone depletion and tropospheric ozone photochemical oxidants, reduction in acidification potential, reduction in eutrophication potential, reduction in abiotic depletion potential for fossil and non-fossil resources, reduced water use (ISO 14044, 2006 and Di Bari & Jorgji, 2021).

The co-benefits finally selected for the stated preferences evaluation are listed and discussed in Section 4.2.

3. Co-benefit assessment, the methodologies

Given that both exercises aim to evaluate the co-benefits, although at different scales (household and community level), we opted for a parallel assessment of the co-benefits at household and community level, because both the stated preferences and the direct costing methods are suitable for some of the co-benefits addressed in both tasks. Therefore, we present a methodology to assess the co-benefits at both the household and community level, using two complementary approaches.

3.1 Assessing co-benefits with direct costing method

This section reports a short description of each of the selected co-benefits from PEBs and the direct cost methodology that can be applied for their economic evaluation (see Table 3.2 for a summary). To quantify the selected co-benefits, physical environmental indicators coming from Di Bari et al. 2024, Di Bari et al. 2022, Di Bari & Jorgji 2021, derived by a life cycle environmental impact assessment of PEBs according with the procedure outlined in Di Bari & Jorgji 2021.

Reduction of construction material and demolition waste

Upgrading buildings and increasing their energy efficiency might lead to reduction, reusing and recycling of waste materials (IEA, 2017). PEB's have the potential to reduce waste. With improved project definition and planning, the reduction, reuse and recycling of materials and waste generated during the construction, renovation, deconstruction, and demolition processes can provide co-benefits (Sharmina, et al., 2009, Kats, 2005, Koppinen & Morrin, 2019).

Co-benefit indicator: Difference in the weight (kg) or volume (m^3) of the various waste categories (e.g., wood, glass, concrete etc.) generated over the lifetime of a PEB compared to the reference nZEB.

Direct costing assessment: Using the data and indicators coming from WP4, and following the recommendation of: The European Commission guide for Cost Benefit Analysis of investment projects (2014), the reduction in waste is valued at the market price of waste and recycling services. The price of waste utilities varies across European countries, meaning that a uniform EU price is lacking (Dohogne, 2014). To overcome this issue, a standard Waste Treatment Cost from the literature (Table 3.1) is used, based on the standard classification system of construction work of the Andalusian Construction Cost Database. (See Vázquez-López et al., 2020 for a detailed description of the methodology of constructing these standard costs).

Waste Treatment Cost (WC) Material(k)	Recycle (WCYk)	Disposal (WCDk)
Mix non-inert	-	70.00 €/t
Mix inert	9.50 €/t	30.00 €/t
Concrete	4.00 €/t	30.00 €/t
Ceramics	6.00 €/t	30.00 €/t
Wood	25.00 €/t	70.00 €/t
Glass	30.00 €/t	70.00 €/t
Bituminous	3.50 €/t	70.00 €/t
Metal	−80.00 €/t	30.00 €/t
Cable	−900.00 €/t	70.00 €/t
Soil	3.00 €/t	30.00 €/t
Isolation	60.00 €/t	80.00 €/t
Gypsum based	60.00 €/t	80.00 €/t
Paper	3.50 €/t	70,00 €/t
Hazardous	-	80,00 €/t

Table 3.1. Waste Treatment Cost. Source: Reproduced from Vázquez-López et al., (2020).

Specifically: The weight (Kg) of construction waste (CW) over the lifetime of the PEB is equal to the sum of the quantities of different waste types in the n life cycle phases evaluated.

$$CW_{PEB} = \sum_{i=1}^{n} Wood_i + Concrete_i + \cdots Cable_i$$

This will be then multiplied by the corresponding "prices" depending on the waste type, and whether it is being disposed of or recycled. Therefore, the cost of construction waste (CoW) for a PEB is given by the following equation:

$$CoW_{PEB} = \sum_{i=1}^{n} WM_{P\,i}(P_{WM})$$

Where $WM_{P\,i}$ represents the specific waste material produced in phase i in a PEB, and $P_{WM})$ represents the corresponding price of disposal/recycling of the specific waste material. To express this as a co-benefit (CB), a comparison is needed with the reference nZEB following the equation:

$$CB_{PEB} = CoW_{PEB} - CoW_{NZEB} = \sum_{i=1}^{n} \quad WM_{P\,i}(P_{WM}) - WM_{N\,i}(P_{WM})$$

Lower operational and maintenance costs

Less exposure to energy price fluctuations could lead to lower operational and maintenance costs in energy efficient buildings (EU, 2020). Furthermore, energy efficient buildings may have lower life cycle costs over the construction and operational phase (Koppinen & Morrin, 2019).

Co-benefit Indicator: Difference in the operational and maintenance hours required over the lifetime of the PEB compared to the reference of the nZEB.

Direct cost assessment: The difference in maintenance and operational hours over the lifetime of a PEB compared to the reference nZEB, can be priced using the average market value of those services.

Mitigation of climate change (GWP)

Energy efficient buildings have a huge potential to mitigate climate change (Lucon et al., 2014). This can derive from lower GHG emissions over the building's life cycle, induced by a lower carbon content of material, and processes. Furthermore, operational emissions can be reduced by more efficient heating and or insulating systems that can lead to a reduction in energy consumption in the building (Bleyl et al., 2019). However, despite the potential of lower GHG emissions, it must also be noted that more advanced and efficient heating and insulating systems employed in PEB's could result in higher embodied emissions, related to carbon intensive production and end of life phases. Literature suggests that GHG emissions will only be lower (providing climate mitigation benefits) during the operational phase of PEB's (Passer et al., 2012; Mirabella et al., 2018). Finally, specific technologies can lead to an increase in the production and use of renewable energy, which will also help to mitigate climate change induced by the use of fossil-fuel energy sources. In addition to these environmental benefits, the reduction in greenhouse gas emissions may yield a financial benefit for building owners. This can occur if environmental certificates can be obtained and then sold in an emissions trading scheme or taxes on fossil fuels can be reduced (Bleyl et al., 2019). In the case of PEBs, it is interesting to evaluate the increase of embodied impacts along with GHG reductions, due to energy credits. Depending on the installed PV surface and the national contexts, energy credits can be converted in GHG credits that potentially payback the initial environmental investment (see Di Bari et al, 2024).

Co-benefit indicator: Difference in the total quantity of GHG emissions (tons of CO_2 or other GHG transformed into CO_2 equivalent) over the lifetime associated with the PEB compared to the reference nZEB, according with EN 15804 + A2 (2020) .

The PEB emission balance is essentially derived from three factors:

3. Total annual energy use (Qu)
4. Annual electricity production (Qp)
5. Embodied emissions in the building material over the complete building lifetime of n years. (EmE(n)).

Following the methodology laid out by Höfler et al., (2020) and Di Bari et al, (2024).the CO_2 emissions savings will be equal to the lifetime embodied emissions of the building plus the difference between electricity delivered to the building from the grid minus electricity exported to the grid multiplied by f(i), the respective CO_2intensity factor (in gCO2e/kWh for electricity) in year i.

$$\Delta(n) = EmE(n) + \sum f(i) \times (Q\text{d} - Q\text{e})$$

Direct cost assessment: To evaluate the benefit of reduced carbon emissions, the Social Cost of Carbon (SCC) can be used. The SCC is a key tool in climate change policy, used in the design and evaluation of mitigation policies, such as energy efficiency standards or emission cuts (see e.g.: Pearce 2003, Griffiths et al., 2012; Nordhaus, 2014, 2017; Rennert and Kingdon 2019). The SCC measures the marginal damage cost of emitting an additional unit of carbon dioxide or other equivalent greenhouse gases into the atmosphere. It is composed of the sum of all future discounted damages from a one unit increase in CO_2. In economic terms, it is the change in the discounted value of economic welfare that results from a unit increase in emissions, thus representing the marginal cost to society. Estimates of the SCC increase over time. This is due to the expectation that the marginal damages in the future from emissions will increase as the economy will be larger and as physical and economic systems are placed under increasing pressure from higher levels of climate change (Griffiths et al., 2012). Another key factor determining the social cost of carbon is the choice of the discount rate. In short, the discount rate places a weight on different time periods, a more extensive discussion can be found in Pearce (1999). This weight can be determined either “positively”, by observing, for instance, how markets’ reward intertemporal investments, or “normatively”, by assigning a subjective evaluation to the present against the future times.

One ton of CO_2 emitted today originates damages for hundreds of years given the long permanence of CO_2 in the atmosphere. Accordingly, a lower discount rate corresponds to a lower “depreciation of the future against the present”, this implies also a higher social cost of carbon and *vice versa*. The SCC is usually calculated using simulation models that link CO_2 eq. emissions with changes in social welfare, known as integrated assessment models (IAMs) (Dietz, 2012).

Employment creation

The implementation of mitigation measures at the building level might induce some macroeconomic effects in terms of employment creation. The investments needed for the execution of these policies creates, albeit mainly in the short term, new business opportunities and employment for energy efficiency service companies (Sharmina et al., 2009, IPCC, 2022). These effects however can be partially counterbalanced by a reduction in opportunities in other sectors, such as the fossil fuel industry. In this regard, the magnitude of these effects will highly depend on the structure of the economy.

Co-benefit indicator: Number of additional jobs created as a result of the PEB compared to the reference nZEB.

Direct cost assessment: Provided the information on the number of additional jobs created as a result of the construction and use of a PEB in comparison with the nZEB, this co-benefit can be directly valued using the average wage in the relevant industry.

Improvement of social welfare

Although, according to the IPCC AR5 definition (IPCC, 2014) direct energy savings are not considered a co-benefit of PEB, the decreased share of energy costs in households’ disposable income can bring an indirect benefit in terms of improved social equity. Indeed, poorer households spend a higher proportion of their earnings on energy, and are at a higher risk of energy poverty. Accordingly, a reduction of energy bills can be “progressive” benefiting more the poorer than the richer contributing to fuel poverty alleviation and social welfare.

Co-benefit indicator: Total energy savings over the lifetime (MWh) of the PEB compared to a nZEB translated in terms of reduction in energy poverty.

Direct cost assessment: According to the methodology of Reuter et al., (2020), the benefit of energy poverty alleviation can be evaluated by measuring the effects of energy savings in PEBs on the financial situation of households belonging to the first income decile (the lowest) in a representative country. As a first step, the method will estimate a percentage change in disposable income given by the following:

$$\frac{\Delta INCe, D1}{INCe, D1}$$

where$INC_{e,D1}$ is the share of energy costs in disposable income of a household in the first income decile.

$$\text{Therefore, the change in } INC_{e,D1}{=}\Delta INC_{e,D1} = [INC_{e,D1}^{0}] - [INC_{e,D1}^{1}]$$
$$= INC_{e,D1}^{0} - [INC_{e,D1}^{0} + (ec * ESHH)]$$

where $INC_{e,D1}^{0}$ is the share of energy costs in disposable income before the energy savings occur, and $INC_{e,D1}^{1}$ after the energy savings, *ec* is the cost of energy per unit and *ESHH* is the average energy savings per household.
This percentage variation can provide an estimation of the social impacts of the energy savings, and the extent to which energy poverty can be alleviated.

Reduction of air pollution

Reducing the harmful effect of air pollution has been identified as a health-related co-benefit of PEB's (Sharmina et al., 2009). Air pollution primarily occurs from the emissions of CO_2, NOx, SO_2, and small particle matters (PM2.5) linked to fossil fuel burning by the buildings (e.g. for heating or cooking purposes) or to electricity use for that share which has a fossil source (Ferreira & Almeida, 2015). These pollutants have harmful effects on human health, being linked with lung cancers, ischemic heart diseases, respiratory illnesses with clear negative impacts on mortality and morbidity (LANCET, 2016). PEBs with their potential to reduce energy use, and also to generate clean energy, can reduce these impacts resulting in significant health gains (IPCC, 2022). Accordingly, this co-benefit is often assessed by quantifying health improvements, such as avoided deaths or illness from reduced air pollution (Ferreira, & Almeida, 2015).

Co-benefit indicator: To evaluate the benefits of reduced air pollution, the difference in physical emissions (kg) of particulate matter across PEBs and nZEBs is used. A similar methodology is followed for any other pollutants linkable to air pollution mortality and morbidity. Then the avoided quantities of pollutants are translated into a change in mortality or morbidity (see Box 1). These, on their turn, can be translated into an economic measure.

Direct-cost assessment: The benefit of reduced air pollution is monetised by multiplying avoided physical emissions of particulate matters by their external costs. CE Delft (2018) for instance, calculated the external or social cost of emitting an additional kg of PM10 or equivalent to be €39.2 by combining epidemiological studies and economic values for human life, (see Box 1).

Box 1: Estimating the economic value of health impacts from reduced PM formation.

The health impacts of air pollution, mortality and morbidity, are often expressed using physical indicators measuring the incidence, such as the number of life year (mortality) or losses to quality of life (morbidity). Indicators such as YOLL, DALY, and QALY are commonly used indicators. YOLL stands for Years of Lost Life, and represents the number of years of life lost as a result of premature mortality. DALY, which stands for Disability-Adjusted Life Years, represents the number of years of life lost due to impaired health. QALY, i.e. Quality-Adjusted Life Years, represents the number of years of "perfect" health. Using these indicators, mortality is given by the "number of life years lost" (DALY's or YOLL's). More often, morbidity is expressed in terms of QALY's. Most European studies evaluating the social costs of air pollution have used the YOLL as an indicator for premature mortality, while using the QALY framework separately to value morbidity impacts. It is suggested that the YOLL framework is more representative of the mechanisms through which environmental pollution damages human health, it tends to reduce life span through diseases, particularly at the end of a person's life. Therefore, YOLL, representing the number of years lost due to premature mortality, more accurately represents the mortality impacts of environmental pollution (de Bruyn & de Vries, 2020).

Estimating the impact on human health from air pollution: To estimate the effect of air pollution on human health (in the form of a change in YOLLs and QALYs) the impact pathway approach is used. This is a methodology that characterises the chain of impacts occurring starting from an emission of a certain pollutant, and ending with a monetised impact on human health. Using first atmospheric modelling that describes the dispersion of an emission and the resulting changes in ambient pollutant concentrations then combining this with concentration response functions, that define how human health responds to the change in concentrations, and finally by employing valuation techniques to value this impact on human health (De Bruyn, 2020). For a more in-depth description of this approach see DEFRA, (2019).

Concentration response functions estimate the impact of emissions on human health. Most epidemiological studies give their results in terms of relative risk, RR, which is the ratio of the incidence observed at two different exposure levels. However, this represents the percentage increase in the relative risk from an increase in the exposure levels of a pollutant, and to quantify the damages one must translate this relative risk to a concentration response function. To do so, the existing risk already present amongst the population for these incidents must be used. The concentration response function expresses the health impacts resulting from a change in exposure to a pollutant (stemming from a change in pollutant concentration).

Translating health impacts into economic figures: After the impact on human health has been estimated through the application of the concentration response functions, the valuation of damage from air pollution can be carried out by using the Value of Statistical Life (VSL) and the Value Of a Life Year (VOLY) approaches. The VSL represents the amount that people are willing to pay to reduce their risk of dying from adverse health conditions. The VOLY also considers the age when death occurs and puts a higher importance on deaths at a young age compared to deaths at an older age. The VOLY is based on the damage costs associated with the loss of life expectancy. It is used with an indicator of the potential years of life lost, e.g., YOLLs. Accordingly, the VSL is used to value the number of deaths, or lives lost, and the VOLY for the value of the aggregate reduction in life expectancy (EEA, 2014). There are different techniques in which they can the VSL and VOLYs can be calculated (e.g., the human capital approach or the willingness to pay approach) and as such there are range of different estimates available. For example, the literature estimates that the VSL for the EU-27 is between USD 1.8 million – 5.4 million (2005-USD), with a base value of USD 3.6 million (EEA, 2014).

The Handbook of Environmental Prices (CE Delft, 2020) combined the approaches of the NEEDS project (NEEDS, 2008), the HRAPIE framework (WHO, 2013) and using the Impact Pathway approach estimated an environmental damage cost per emission The impacts on human health are responsible for most of these damage costs per emission. Hence, they can be used as an estimation for health benefits due to reduced air pollution. For a more detailed description of the methods, see also (De Bruyn, 2020; CE Delft, 2018).

Reduced ozone depletion (ODP)

Notwithstanding existing regulations, part, although minimal, of the emissions from buildings can be ozone-layer depleting substances. The negative effects of the thinning of the ozone layer range from impacts on human health to damages on ecosystems.

Co-benefit indicator: Difference in emissions of CFC equivalent substances (ODP, according to EN 15804 + A2 (2020) and Di Bari & Jorgji, (2021)) over the lifecycle phases of a PEB compared to the reference case nZEB

Direct-cost assessment: The benefit of reduced negative impact on the ozone layer will be evaluated by multiplying avoided physical emissions of CFC equivalent substances by their external costs. CE Delft (2018) calculated the external or social cost of emitting an additional kg of CFC equivalent added to the atmosphere into €30.40.

Reduced formation potential of tropospheric ozone photochemical oxidants (POCP)

The LCA tool can provide a Lifecycle Impact Assessment (LCIA) of the Photochemical Ozone Creation Potential (POCP, according to EN 15804 + A2 (2020) and Di Bari & Jorgji, (2021)). LCA analyses can be provided on technology level as well as higher solution set and building level.

Co-benefit indicator: The difference in weight (kg) of Ethen equivalent emissions over the life cycle of a PEB and the reference nZEB.

Direct-cost assessment: The external or social cost of Photochemical oxidant formation is given as €1.15 per kg of non-methane volatile organic compounds (NMVOC) emitted (CE Delft, 2018).

Reduced acidification potential (AP)

Acidification can cause corrosion to infrastructure and buildings and can have negative impacts on agricultural crops and biodiversity. AP is derived according to EN 15804 + A2 (2020) and Di Bari & Jorgji, (2021).

Co-benefit indicator: The difference in emissions of weight (kg) of sulphur dioxide (SO_2) equivalent over the life cycle of a PEB and the reference nZEB.

Direct-cost assessment: The external or social cost of a unit of sulphur dioxide emissions is €4.97 per kg (CE Delft, 2018).

Reduced eutrophication potential (EP)

Certain emissions associated with building technologies can result in increased eutrophication potential, which can damage ecosystems. EP is derived according to EN 15804 + A2 (2020) and Di Bari & Jorgji, (2021).

Co-benefit indicator: The difference in emissions of kg of phosphate equivalent over the life cycle of a PEB and the reference nZEB.

Direct-cost assessment: The external or social cost of freshwater eutrophication is given as €1.86 per kg of phosphate equivalent (CE Delft, 2018).

Reduced abiotic depletion potential for non-fossil resources (ADPE)

The LCA tool reports the abiotic depletion potential for non-fossil resources[1] (ADPE is derived according to EN 15804 + A2 (2020) and Di Bari & Jorgji, (2021) for the Cultural-E heating and cooling technologies.

Co-benefit indicator: The difference in emissions of kg of Sb (Antimony) equivalent over the life cycle of a PEB and the reference nZEB.

Direct-cost assessment: The external or social cost of resource use, minerals and metals is given as €1.64 per kg of Sb equivalent (Trinomics, 2020).

Reduced Abiotic depletion potential for fossil resources (ADPF)

Similarly, the LCA tool reports the abiotic depletion potential for fossil resources for the Cultural-E heating and cooling technologies. ADPF is derived according to EN 15804 + A2 (2020) and Di Bari & Jorgji, (2021)

Co-benefit indicator: The difference in energy (megajoule, Mj) related over the life cycle of a PEB and the reference nZEB.

Direct-cost assessment: The external or social cost of fossil resource use is given as €0.0013 per Mj (Trinomics, 2020).

Reduced water use

Improving energy and overall efficiency in buildings can lead to a reduction in water consumption. The LCA tool reports the use of net freshwater (FW) according to EN 15804 + A2 (2020) and Di Bari & Jorgji, (2021).

Co-benefit indicator: The difference in net freshwater use over the life cycle of a PEB and the reference nZEB.

Direct-cost assessment: The external or social cost of water use is given as €0.00499 per m3 of water equivalent (Trinomics, 2020).

[1] Abiotic depletion describes the decrease of availability of total reserve functions of resources: the more abundant a material is (like sand or gravel), the lower its contribution to depletion compared to reserves (Herczeg et al., 2014).

Co-benefit	Indicator	Direct cost assessment
Reduction of construction material and demolition waste.	Difference quantities of the various waste categories over lifetime of PEB compared to nZEB.	A standard Waste Treatment Cost from the literature.
Lower operational and maintenance costs.	Difference in the operational and maintenance hours over the lifetime of the PEB compared to nZEB.	Average market value of those services.
Mitigation of climate change.	Difference in the total quantity of CO_2 emissions over the lifetime of PEB compared to nZEB.	The social cost of carbon.
Employment creation.	Number of additional jobs created as a result of the construction of a PEB compared to a nZEB.	The average wage in the relevant industry.
Improvement of social welfare.	Total energy savings over the lifetime (MWh) of the PEB compared to a nZEB.	Translated in terms of reduced energy poverty. Demonstrating the effect of energy savings on the financial situation of the lowest income decile.
Reduction of air pollution.	Difference in physical emissions (kg) of particulate matter over the lifetime of the PEB compared to a nZEB.	The external or social cost of PM10 emissions or equivalent, €39.2.
Reduced ozone depletion.	Difference in emissions of CFC equivalent substances over the lifecycle phases of a PEB compared to the reference case nZEB	The external or social cost of emitting additional kg of CFC or equivalent, €30.40.

Reduced formation potential of tropospheric ozone photochemical oxidants.	The difference in kg of Ethen equivalent emissions over the life cycle of a PEB compared to a nZEB. Direct-cost assessment:	The external or social cost of Photochemical oxidant formation is given as €1.15 per kg of non-methane volatile organic compounds (NMVOC) emitted.
Reduced acidification potential.	Difference in emissions of kg of phosphate equivalent over the life cycle of a PEB compared to a nZEB.	The external or social cost of a unit of sulphur dioxide emissions is €4.97 per kg.
Reduced eutrophication potential.	Difference in emissions of kg of phosphate equivalent over the life cycle of a PEB compared to a nZEB.	The external or social cost of freshwater eutrophication is given as €1.86 per kg of phosphate equivalent
Reduced abiotic depletion potential for non-fossil resources.	Difference in emissions of kg of Sb (Antimony) equivalent over the life cycle of a PEB compared to a nZEB.	The external or social cost of resource use, minerals and metals is given as €1.64 per kg of Sb equivalent.
Reduced Abiotic depletion potential for fossil resources.	The difference in energy (Mj) related over the life cycle of a PEB compared to a nZEB.	The external or social cost of fossil resource use is given as €0.0013 per Mj.
Reduced water use.	The difference in net fresh water use over the life cycle of a PEB compared to a nZEB.	The external or social cost of water use is given as €0.00499 per m3 of water equivalent.

Table 3.2. Summary of co-benefits, indicators, and direct cost assessment

3.2 Assessing co-benefits with stated preference methods

While for some co-benefits a "price tag" can be inferred from their direct or indirect relation with goods and services for which a market exists, some co-benefits are inherently difficult to evaluate in monetary terms. For these co-benefits, a stated preference approach will be used. For example, the economic value of improved indoor air quality has no market price or substitute good, and co-benefits can be estimated by means of a methodology that elicit preferences for air quality through a mechanism that brings respondents to express their preferences for the good lacking a standard price tag. In a nutshell, these approaches infer the willingness to pay for the co-benefit under scrutiny from a representative sample of respondents.

A widely applied stated preference method is the Discrete Choice Experiment approach, (DCEs), which can provide quantitative information on the relative importance of various characteristics that influence choices by looking at the trade-offs between these factors as emerges from the reaction of a sample of respondents to an experimental setting.

We originally planned to conduct this study using a DCE, but the use of standard DCE setting proved infeasible in our case for the reasons explained below, and we had to resort to a (hybrid) stated preferences approach that draws both from choice experiments and from a rental value elicitation in a hypothetical setting that is resonant with the hedonic pricing approach.

In a DCE setting, individual decisions about the object of the choice, be it a good, a service or a policy action, are determined by its characteristics, or so-called *attributes*. DCE are based on data collected by asking several respondents about their preferences.

In a DCE setting respondents are asked to choose among various hypothetical choices, described in terms of a series of characteristics, one of which is a monetary cost. Econometric techniques allow the estimation of the value of the willingness to pay (WTP) that is most consistent with the choices expressed by the respondents. This requires identifying a payment vector which can credibly capture the willingness to pay for energy-related improvements for the target population. It was ultimately the impossibility to identify such a suitable cost attribute, along with the specific issues of the topic of energy efficiency in buildings, that prompted us to adopt our innovative approach.

The rate of adoption of energy-efficiency technologies and micro-generation equipment has historically been very slow almost everywhere. Policies seeking to promote their adoption have typically relied on combinations of regulations on new products and building codes, as well as subsidies and incentives offered directly or in the form of tax incentives to homeowners.

Earlier studies have sought to assess the effectiveness of tax incentives and subsidies to energy efficiency renovations by taking advantage of variation in the relevant policies (Charlier and Risch, 2012; Alberini, Bigano and Boeri, 2013; Charlier 2015), and in some cases explored the potential for free riding, namely the tendency to avail themselves of incentives even though the renovations would have been done anyway (Grosche and Vance, 2009; Alberini, Bigano and Boeri, 2013; Alberini, Gans and Towe, 2016).
Data limitations, the low rate of adoption of new residential energy technologies and insufficient variation in the policies, however, make it difficult to estimate a renovation or technology adoption "curve" and to predict with precision how many homeowners will indeed adopt new technologies at incentive levels above and beyond those already in existence.

An alternative is to use stated preference data, asking people whether they would adopt certain technologies, do certain renovations or choose to live in homes with certain characteristics under well spelled out, hypothetical conditions. Stated preference studies have uncovered, for example, the rate at which people discount future savings on the energy bills (Alberini, Banfi, and Ramseier, 2013; Newell and Siikamäki, 2015), the importance of risk aversion (Qui et al., 2014; Schleich et al. 2019), but the preference elicitation methods therein (typically, discrete choice experiments) do not lend themselves to predicting how many homeowners will actually implement certain renovations or how many homes with specified energy efficiency features will be bought or sold in actual markets. Besides energy use, but still applying a stated preference approach in a residential housing context, Guignet and Alberini (2014) check whether the health risk posed by poor air quality can influence real estate prices, by asking Italian and British homeowners to choose among hypothetical variants of their home differing in terms of price and mortality risks from air pollution. Mihailova et al., 2022 use a DCE approach to evaluate the attitudes of the Swiss population towards a large-scale deployment of PEDs in their country, by inquiring about the features of a PED the respondents would be willing participate in.

Although there have been studies about the evaluation of environmental amenities combining stated preferences with a hedonic prices model based on actual data from real estate markets (e.g. Phaneuf et al., 2013), we are not aware of attempts in this sense applied to residential energy use.

In an effort to circumvent these problems, we developed a survey questionnaire where we ask respondents to tell us the rental value of their home, under the current conditions and under seven hypothetical scenarios that entail the presence or absence of local energy networks, centralized air filtration and ventilation systems, and combinations of sensors and software that optimize the energy used by appliances and for heating (or cooling), while maintaining the thermal comfort of the home

We believe that asking respondents to estimate the rental value of the home under the current and hypothetical conditions answers directly the question whether homeowners expected improvements in energy security and efficiency to be capitalized into the price of or rental income from the home. Moreover, during the development of the survey questionnaire we felt that asking people to express their judgment of the market potential of their home created a more neutral "survey environment" and helped reduced strategic incentives often associated with discrete choice experiments or contingent valuation questions.

This is a hybrid, innovative approach. It resonates with the DCE literature inasmuch the co-benefits are submitted for evaluation by the respondents by presenting them a series of evaluation tasks describing the dwelling in terms of attributes capturing the co/benefits. However, since it elicits directly in the rental price for dwellings describe in terms of several attributes in a hypothetical setting, our approach to some extent resonates also with the hedonic pricing approach.

Our value elicitation exercise is centred on asking our respondent to estimate the rental value of their dwelling. Many surveys conducted by the federal government in the US ask people to estimate the value of the home they live in, if it was sold in today's real estate market. These include the American Housing Survey,[2] the American Community Survey,[3] and the US Consumer Expenditure Survey.[4] In Europe, the EU-SILC survey, deployed routinely in the EU Member States, asks this question every three years since 2007 (Törmälehto and Sauli, 2013, Eurostat, 2022). One would imagine the quality of such predictions to depend on familiarity with the real estate market. Benitez-Silva et al. (2015), for example, find that US homeowners overpredict the values of their home by some 8% on average.

[2] See https://www.census.gov/programs-surveys/ahs/tech-documentation/def-errors-changes.html.
[3]See https://www2.census.gov/programs-surveys/acs/methodology/questionnaires/2020/quest20.pdf.
[4]See https://www.bls.gov/cpi/factsheets/owners-equivalent-rent-and-rent.htm#:~:text=The%20BLS%20uses%20data%20from,the%20expenditure%20weight%20for%20rent.
The Consumer Expenditure Survey, in particular, elicits the Owners' Equivalent Rent (OER), asking homeowners to estimate how much they believe their home would rent for per month if they were to put it on the rental market, unfurnished and without utilities included. These data are often used to measure housing market trends and contribute to the Consumer Price Index (CPI).

3.2.2 Empirical assessment of the value of co-benefits in practice

Our study covers two major European countries—Germany and France—which boast dramatically different sources of energy. We focused on the regions along the border between the two countries, arguing that by doing so we would ensure similar climate (and hence reliance on space heating and cooling) and a relatively similar housing stock.[5] Attention is restricted to persons that live in the homes they own.

For each country, we created four "bands" at increasing distance from the border (see Figure **3.1**.) and sought to obtain a final sample where 50% of the respondents live in zone 1 (the closest to the border), 30% in zone 2 (adjacent to zone 1), and 20% in zone 3 (adjacent to zone 2). Zone 4 was intended as a reserve, in case it would prove impossible to reach our target of 2000 completed questionnaires. The four zones are densely populated, and include large cities such as Stuttgart, Karlsruhe, Mannheim, Freiburg and others in Germany, as well as Strasbourg, Reims, Mulhouse, Dijon and Metz in France.

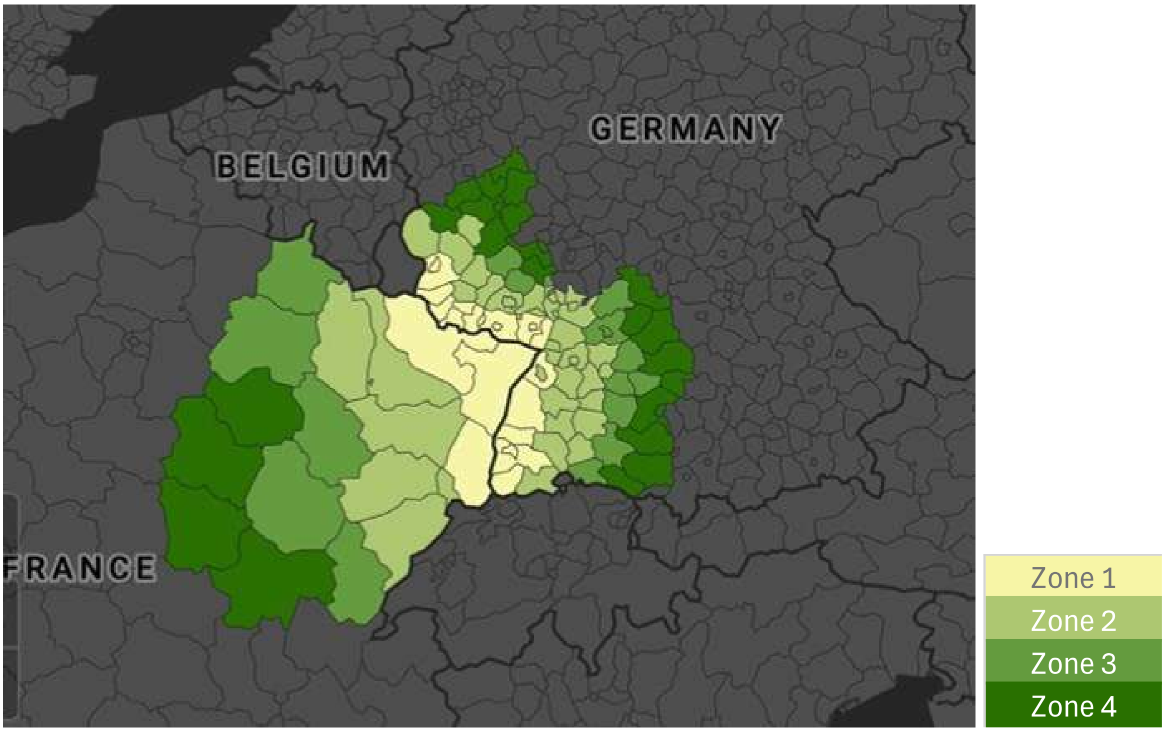


Figure 3.1. Geographical subdivision of the area of the study for sampling quotas

[5] The study areas are in Rheinland-Pfalz, Saarland, and Baden-Württemberg in Germany; Alsace-Lorraine, Champagne- Ardenne, Bourgogne e Franche-Comté in France.

Our sampling plan also spelled out that the final sample should be comprised of an even number of men and women. We did not specify any other requirements in terms of distribution of income or education, although one would expect homeowners to be somewhat older, and possibly better educated and wealthier than the average person in the population.

We obtained a total of 2051 completed questionnaires, 41 of which were from zone 4. Table 3.**3** reports our original quota targets and their actual sample shares, showing that the Germany sample ended up underrepresenting zone 1 residents and overrepresenting zone 2 residents.

A clear and unambiguous language is crucial in describing attributes and levels to make sure that their interpretation by the respondents is the same as the one of the drafters of the questionnaire. In the case of the evaluation of co-benefits of PEBs, the selection of attributes and of their levels has been carried out in cooperation with technical partners with a deep knowledge of the characteristics of nZEB and PEB.

	Target (%)	German sample (%)	French sample (%)
Border proximity zone			
1	50	38.6	47.29
2	30	37.8	28.73
3	20	21.5	22.07
4	0	2.1	1.9
Gender			
male	50	48	49.48
female	50	51.8	50.14
non-binary	0	0.1	0.29
prefer not to say	0	0.1	0.1

Table 3.3. **Sampling plan and actual shares of the sample by area and gender**

The choice of attributes went through a number of steps. First, the original Cultural-E list of co-benefits was screened in view of the difficulty to convey the precise meaning of co-benefits to respondents, due to the technical complexity, or the inherent ambiguity of their definition. Since the resulting list selected co-benefits was still too long to be submitted to respondents without inducing excessive fatigue, co-benefits were then grouped within clusters according to their relative similarity, as shown in the

Table 3.4.

Indoor Air Quality Cluster
Indoor air quality
Health improvement
Improvement of health conditions / Reduction of work leave (smart working)
Reduction of psychological effects
Increase in productivity (smart working)
Building's real estate value Cluster
Easier to sell / rent at higher real estate prices
Increase in the value of the building
Energy consumption Cluster
Reduction of energy consumptions
Reduction of energy consumption costs
Lower cost of energy
Less need for energy subsidies
Reduction of dependence on fossil fuels
Indoor Comfort Cluster
Thermal comfort
Acoustic comfort
Visual comfort/quality of natural light indoor
Local Pollution reduction Cluster
Biodiversity protection
Environmental resources protection
Conservation of ecosystems
Energy security
Easy of use
Lower maintenance costs
Reduction of CO_2 emissions
Resilience to climate change
Safety

Table 3.4. Co-benefit preliminary clustering for stated preferences evaluation

This clustering exercise highlighted the main areas of relevance for co-benefits. While some clusters attract several co-benefits, six of them contain a single co-benefit. This exercise narrowed the number of possible number of attributes to 11, which is still high for state preference purposes. A further round of interaction with technical partners reduced the list of attributes to the following:

- **Energy Balance**: It covers the ability of the building to cope with energy consumption, energy efficiency and energy security. Note that the first two features can also be analysed via direct costing, while the third one is better tackled by means of stated preference methods. Despite the partial suitability for direct costing, we thought at this stage, to keep the energy consumption and energy efficiency angles because those are at the core of the definition of Plus Energy Buildings. Moreover, energy security, a key element in this category, does not lend itself to direct costing assessment.

- **Indoor Environmental Quality:** It covers the highly subjective perception of thermal comfort, visual comfort, and acoustic comfort by the respondent.

- **Adaptability:** the ability of the building to adapt to user needs. It includes the control that a user can exercise over a technology and how the presence of this technology offers more possibilities to the user (columns then purchase of electric car, etc.). Interestingly, this includes the possibility for the user of joining an energy community (e.g. the community of the people living in a block where they share a renewable electricity generation plant through a micro smart grid).

- **Price:** A crucial consideration is the credibility as a means for capturing the costs actually relevant in the specific situation of the respondent, of the proposed payment instrument. In our case, the identification of the payment instrument depends on the nature of the occupancy of the dwelling (i.e., whether respondents rent or own their place) and the likelihood of purchasing a new place soon. In other words, it would be hardly credible to ask people who are renting and intend to keep renting in the foreseeable future, how much they would be willing to pay in to purchase a new house with the features of a Plus Energy Building: most likely, they have no such willingness for any kind of buildings. However, they might be willing to pay a higher rent for living in a PEB. Similarly, people who just moved into their current place are unlikely to be willing to embark on a new removal any time soon, but they may consider spending money for upgrading their place if they have not already done so. People who have been living in their current place for several years may be the ones for whom pondering about the whole price of a new place may make sense, and this can well happen for a PEB. Moreover, for owners it makes sense to consider, besides the investment, the operation and maintenance (O&M) costs, whereas for renters, they usually do not matter because they are taken care of by the property owner. To take care of these different classes of respondents, we originally planned to resort to a split—sample approach, whereby we sort our respondents according to the nature of occupancy and, in case of owners, the time they have been living at their current place and propose them the payment instrument most suitable to them. However, we realised that this approach is still fraught with practical problems likely to seriously undermine the feasibility of a DCE. We thus resorted to the hybrid rent elicitation mechanism described in the previous subsection.

For these attributes, preliminary ranges of variation for different levels of building (i.e., base-good-excellent) were identified with the support of Eurac Research, Ca' Foscari University and other technical partners (e.g., Nobatek and Steinbeis). However, these ranges were eventually superseded by our final choice of the attributes, and we do not report them here. A description of the final list of the attributes is included in the description of the final questionnaire below. They cover the energy security angle of the Energy Balance class of co-benefits, and they provide a deep coverage of the Indoor Environmental Quality and Adaptability classes. The price, as mentioned above, is not treated as an attributed but elicited directly through our rental value elicitation mechanism.

4. Results

4.1 Results for the direct costing method

4.1.1 Introduction

As part of WP5 of the Cultural-E project the following "fiche" reports the evaluation of the co-benefits that can be associated with a Plus Energy Building (PEB) applying a direct cost methodology to the Italian case study.

As defined in chapter 1, co-benefits are "additional positive effects brought by a policy measure, that occur regardless of and in addition to the originally predetermined policy goals (AR5, 2014)." Consequently, the current assessment does not evaluate the energy generation potential of the PEB, given that this is, indeed, its primary purpose.

Different methodologies are available for co-benefit evaluation. Direct costing here described, attempts to associate a straight monetary value to a quantifiable source (i.e. a performance indicator) of co-benefits.

This can be more easily feasible when co benefits can be linked to a "use" on its turn associated to material aspects transiting through "market transactions". A typical example is a higher or lower use of say "building materials" commonly bought and sold in standard markets. This can be however possible also for "materials" not directly "priced" by demand and supply interactions. A typical example is emission of pollutants in the atmosphere, whose damage can be monetized applying different methodologies to quantify external costs (see e.g.: Rennert & Kingdon, 2019)

Following this methodology, we hereby evaluate the co-benefits associated with a PEB representative of the Italian context.

4.1.2 The methodology

To apply the direct cost methods the following steps have been followed:

1. co-benefit categories were identified as listed in (Bosello et al. 2024) Table 3.2. They are reported in Table 4.1 below (first column);
2. co-benefit categories were matched to specific environmental indicators calculated by University of Stuttgart (Cultural-E D4.5: (Di Bari and Jorji, (2021), table 1 second column) based on EN 15804 +A1. The study, consisting in a life-cycle assessment, computes a list of indicators "per square meter per year" of three different types of buildings (see Table 4.2 below).
3. Monetary evaluations were attributed to each indicator through a literature review (the list of money reference can be found in the file "Social prices for

LCA.xlsx", available in the Cultural-E Community on the Zenodo repository) while the source literature is reported at the end of this document). Whenever possible, ranges, (low to high cost estimations) for the monetary values have been reported, to communicate the uncertainty beyond the assessment and test its robustness. In the cases of materials for recycling, disposal of radioactive wastes, disposal of hazardous and non-hazardous wastes only one cost reference has been found.

The final evaluations of co-benefits were performed comparing (calculating the difference between) three building types: Building A, Building B (only Italian case, smaller), Building C (reference nZEB), see below Charts 4.1-4.12 and Table 4.3. As anticipated, it is worth stressing that not all potential co-benefits are directly linkable to direct economic values. Furthermore, the unavailability of specific co-benefit indicators, can prevent the assessment of co-benefits even though economic evaluations are in principle available. Specifically (see Table 4.1), due to a lack of information, in the present assessment it was not possible to quantify indicators of:

- operation and maintenance activity,
- employment creation,
- air pollution.

Accordingly, the potential co-benefits associated to these categories were not computed. Furthermore, no data were available to measure changes in energy poverty.

Table 4.1. List of co-benefits, indicators, and money metric for the direct cost assessment (Deliverable D5.2 - Guidelines to assess the co-benefits of Plus Energy Buildings)

Co-benefit	Indicator	Direct cost assessment
Reduction of construction material and demolition waste.	Difference quantities of the various waste categories over lifetime of PEB compared to nZEB. **HWD**	A standard Waste Treatment Cost from the literature. [Vázquez-López et al, 2020]
Lower operational and maintenance costs.	Difference in the operational and maintenance hours over the lifetime of the PEB compared to nZEB. **Not available**	Average market value of those services.
Mitigation of climate change.	Difference in the total quantity of CO2 emissions over the lifetime of PEB compared to nZEB. **GWP**	The social cost of carbon. [Rennert & Kingdon, 2019]
Employment creation.	Number of additional jobs created as a result of the construction of a PEB compared to a nZEB. **Not available**	The average wage in the relevant industry.
Improvement of social welfare.	Total energy savings over the lifetime (MWh) of the PEB compared to a nZEB.	Reduction in energy poverty. Demonstrating the effect of energy savings on the financial situation of the lowest income decile. **Not available**
Reduction of air pollution.	Difference in physical emissions (kg) of particulate matter over the lifetime of the PEB compared to a nZEB. **Not available**	The external or social cost of PM10 emissions or equivalent, €39.2. [CE Delft, 2018]
Reduced ozone depletion.	Difference in emissions of CFC equivalent substances over the lifecycle phases of a PEB compared to the reference case nZEB **ODP**	The external or social cost of emitting additional kg of CFC or equivalent, €30.40. [CE Delft, 2018]
Reduced formation potential of tropospheric ozone photochemical oxidants.	The difference in kg of Ethen equivalent emissions over the life cycle of a PEB compared to a nZEB. **POCP**	The external or social cost of Photochemical oxidant formation is given as €1.15 per kg of non-methane volatile organic compounds (NMVOC) emitted. [CE Delft, 2018]
Reduced acidification potential.	Difference in emissions of kg of phosphate equivalent over the life cycle of a PEB compared to a nZEB. **AP**	The external or social cost of a unit of sulphur dioxide emissions is €4.97 per kg. [CE Delft, 2018]

Reduced eutrophication potential.	Difference in emissions of kg of phosphate equivalent over the life cycle of a PEB compared to a nZEB. **EP**	The external or social cost of freshwater eutrophication is given as €1.86 per kg of phosphate equivalent. [CE Delft, 2018]
Reduced abiotic depletion potential for non-fossil resources.	Difference in emissions of kg of Sb (Antimony) equivalent over the life cycle of a PEB compared to a nZEB. **ADPE**	The external or social cost of resource use, minerals and metals is given as €1.64 per kg of Sb equivalent. [Trinomics, 2020]
Reduced Abiotic depletion potential for fossil resources.	The difference in energy (Mj) related over the life cycle of a PEB compared to a nZEB. **ADPF**	The external or social cost of fossil resource use is given as €0.0013 per Mj.[Trinomics, 2020]
Reduced water use.	The difference in net fresh water use over the life cycle of a PEB compared to a nZEB. **FW**	The external or social cost of water use is given as €0.00499 per m3 of water equivalent. [Trinomics, 2020]

Table 4.2. Unit costs and sources

	unit cost					
Indicator	**low**	**medium**	**High**	**impact/m²*y Unit**	**Price Unit**	**Source**
Total use of renewable primary energy resources (**PERT**)	0.02 €	0.03 €	0.05 €	MJ	€/MJ	Our computation*
Total use of non-renewable primary energy resource (**PENRT**)	0.01 €	0.01 €	0.01 €	MJ	€/MJ	Our computation*
Global warming potential (**GWP**)	0.04 €	0.28 €	0.53 €	kg CO2-Eq	$2022/kg CO2	Tol, 2023
Depletion potential of the stratospheric ozone layer (**ODP**)	22.10 €	30.40 €	45.70 €	kg R11-Eq	€2015/kg CFC-eq.	CE Delft, 2018
Acidification potential (**AP**)	0.53 €	4.97 €	5.66 €	kg SO2-Eq	€2015/kg SO2-eq.	CE Delft, 2018
Eutrophication potential (**EP**)	0.25 €	1.86 €	2.11 €	kg Phosphat-Eq	€2015/kg P-eq.	CE Delft, 2018
Formation potential of tropospheric ozone photochemical oxidants (**POCP**)	0.84 €	1.15 €	1.84 €	kg Ethen-Eq	€2015/kg NMVOC-eq.	CE Delft, 2018
Abiotic depletion potential for non-fossil resources (**ADPE**)	0.00 €	1.64 €	6.53 €	kg Sb-Eq	€2018/kg Sb eq	Trinomics, 2020
Abiotic depletion potential for fossil resources (**ADPF**)	0.00 €	0.00 €	0.01 €	MJ	€2018/MJ	Trinomics, 2020
Material for Energy Recovery (**MER**)	-0.32 €	-0.43 €	-0.55 €	kg	€/MJ	Our computation*
Materials for recycling (**MFR**)	2.83 €	2.83 €	2.83 €	kg	€/kg	Vázquez-López et al., 2020
Radioactive waste disposed (**RWD**)	4.00 €	4.00 €	4.00 €	kg		enea, 2023
Non-hazardous waste dispose (**NHWD**)	0.03 €	0.03 €	0.03 €	kg	€/kg	Vázquez-López et al., 2020
Hazardous waste disposed (**HWD**)	0.08 €	0.08 €	0.08 €	kg	€/kg	Vázquez-López et al., 2020
Use of net fresh water (**FW**)	0.00 €	0.00 €	0.24 €	m3	€/m3	Trinomics, 2020
Use of non-renewable secondary fuels (**NRSF**)	0.01 €	0.01 €	0.01 €	MJ	€/MJ	Our computation*
Use of renewable secondary fuels (**RSF**)	0.02 €	0.03 €	0.05 €	MJ	€/MJ	Our computation*
Input of secondary material (**SM**)	2.83 €	2.83 €	2.83 €	kg	€/kg	Vázquez-López et al., 2020
Renewable primary energy as energy carrier (**PERE**)	0.02 €	0.03 €	0.05 €	MJ	€/MJ	Our computation*
Primary energy resources used as raw materials (**PERM**)	0.01 €	0.01 €	0.01 €	MJ	€/MJ	Our computation*
Non-renewable primary energy as energy carrier (**PENRE**)	0.01 €	0.01 €	0.01 €	MJ	€/MJ	Our computation*

Non-renewable primary energy as material utilization (**PENRM**)	0.01 €	0.01 €	0.01 €	MJ	€/MJ	Our computation*
Exported electrical energy (**EEE**)	0.02 €	0.03 €	0.05 €	MJ	€/MJ	Our computation*
Exported thermal energy (**EET**)	0.02 €	0.03 €	0.05 €	MJ	€/MJ	Our computation*

* Description of the methodology can be found in appendix

4.1.3 The Italian case study

DESCRIPTION

The building types that are contrasted are representative of the Italian context. The buildings have the following characteristics, as described in Cultural-E D6.3 (Leis and Di Bari, 2023):

- Building A consists of 3 floors, 7 dwellings, surface area of approximately 75 m²/dwelling, total area of 622 m². Furthermore, ceiling fans are installed to increase thermal comfort, Active Window System (AWS) with integrated venetian blinds is installed to control solar gains and the cloud-based House Management System (HMS) will be used to manage the house systems
- Building B (slightly smaller), consists of a total area of 520 m². It has the same envelope as Building A. It is equipped with a PV-System of 5,5 kWp per apartment and a battery of 6 kWh per apartment. Furthermore, ceiling fans are installed to increase thermal comfort, Active Window System (AWS) with integrated venetian blinds is installed to control solar gains and the cloud-based House Management System (HMS) will be used to manage the house systems.
- Building C. This is the reference case. In accordance with the Cultural-E consortium decision it is a nZEB. It consists of 4 floors, 9 dwellings with a total area of 789 m². It has a decentralized air-water Heat pump for heat and DHW production and does not have controlled mechanical ventilation with heat recovery. The electricity produced by the 1,5 kWp per apartment PV system is fed in the grid. Building C is equipped with standard automation.

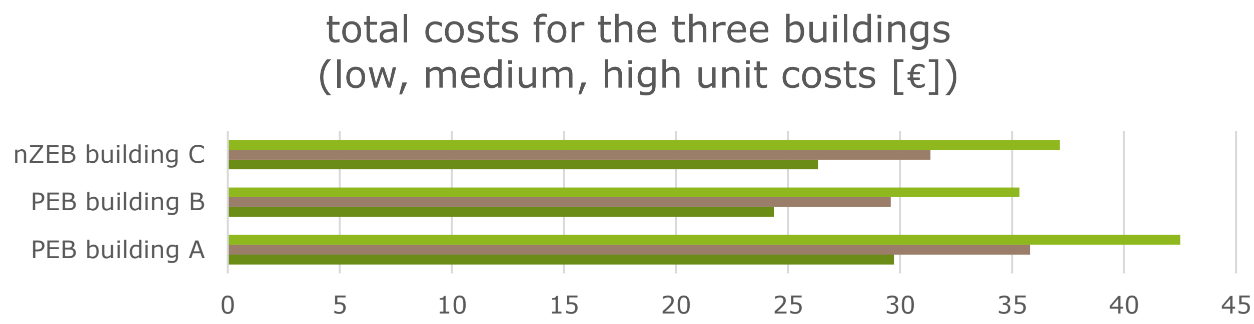
RESULTS

Table 4.3 reports extensively the calculation done, while Charts 4.1 to 4.4 visualize the results of the procedure.

Table 4.3. Calculation of costs, Italian case study (€)

	PEB Building A				PEB Building B				nZEB Building C			
Indicator	impact/m²*y	A - low	A - medium	A - high	impact/m²*y	B - low	B - medium	B - high	impact/m²*y	C - low	C - medium	C - high
PERT	38.199	0.69 €	1.24 €	1.79 €	38.362	0.69 €	1.24 €	1.80 €	47.462	0.85 €	1.54 €	2.22 €
PENRT	188.450	2.58 €	2.62 €	2.66 €	155.137	2.13 €	2.16 €	2.19 €	176.897	2.42 €	2.46 €	2.49 €
GWP	18.174	0.73 €	5.13 €	9.54 €	14.609	0.58 €	4.13 €	7.67 €	13.412	0.54 €	3.79 €	7.04 €
ODP	0.000	0.00 €	0.00 €	0.00 €	0.000	0.00 €	0.00 €	0.00 €	0.000	0.00 €	0.00 €	0.00 €
AP	0.035	0.02 €	0.17 €	0.20 €	0.030	0.02 €	0.15 €	0.17 €	0.029	0.02 €	0.14 €	0.16 €
EP	0.005	0.00 €	0.01 €	0.01 €	0.004	0.00 €	0.01 €	0.01 €	0.004	0.00 €	0.01 €	0.01 €
POCP	0.006	0.00 €	0.01 €	0.01 €	0.006	0.00 €	0.01 €	0.01 €	0.011	0.01 €	0.01 €	0.02 €
ADPE	0.000	0.00 €	0.00 €	0.00 €	0.000	0.00 €	0.00 €	0.00 €	0.000	0.00 €	0.00 €	0.00 €
ADPF	174.894	0.00 €	0.23 €	1.19 €	145.556	0.00 €	0.19 €	0.99 €	171.853	0.00 €	0.22 €	1.17 €
MER	0.000	0.00 €	0.00 €	0.00 €	0.000	0.00 €	0.00 €	0.00 €	0.108	-0.03 €	-0.05 €	-0.06 €
MFR	0.002	0.00 €	0.00 €	0.00 €	0.001	0.00 €	0.00 €	0.00 €	0.027	0.08 €	0.08 €	0.08 €
RWD	0.005	0.02 €	0.02 €	0.02 €	0.004	0.01 €	0.01 €	0.01 €	0.002	0.01 €	0.01 €	0.01 €
NHWD	1.269	0.04 €	0.04 €	0.04 €	1.162	0.04 €	0.04 €	0.04 €	1.871	0.06 €	0.06 €	0.06 €
HWD	0.003	0.00 €	0.00 €	0.00 €	0.002	0.00 €	0.00 €	0.00 €	0.001	0.00 €	0.00 €	0.00 €
FW	0.079	0.00 €	0.00 €	0.02 €	0.079	0.00 €	0.00 €	0.02 €	0.623	0.00 €	0.00 €	0.15 €
NRSF	8.415	0.12 €	0.12 €	0.12 €	7.915	0.11 €	0.11 €	0.11 €	7.538	0.10 €	0.10 €	0.11 €
RSF	4.554	0.08 €	0.15 €	0.21 €	10.946	0.20 €	0.35 €	0.51 €	3.599	0.06 €	0.12 €	0.17 €
SM	7.801	22.07 €	22.07 €	22.07 €	6.244	17.67 €	17.67 €	17.67 €	6.613	18.71 €	18.71 €	18.71 €
PERE	37.951	0.68 €	1.23 €	1.78 €	38.274	0.69 €	1.24 €	1.79 €	35.725	0.64 €	1.16 €	1.67 €
PERM	0.666	0.01 €	0.01 €	0.01 €	0.595	0.01 €	0.01 €	0.01 €	12.626	0.17 €	0.18 €	0.18 €
PENRE	175.064	2.40 €	2.43 €	2.47 €	142.110	1.95 €	1.98 €	2.00 €	140.842	1.93 €	1.96 €	1.99 €
PENRM	17.611	0.24 €	0.24 €	0.25 €	17.827	0.24 €	0.25 €	0.25 €	46.942	0.64 €	0.65 €	0.66 €
EEE	0.739	0.01 €	0.02 €	0.03 €	0.503	0.01 €	0.02 €	0.02 €	1.944	0.03 €	0.06 €	0.09 €

EET	1.832	0.03 €	0.06 €	0.09 €	1.216	0.02 €	0.04 €	0.06 €	4.604	0.08 €	0.15 €	0.22 €
TOTAL		**29.73 €**	**35.81 €**	**42.51 €**		**24.37 €**	**29.59 €**	**35.33 €**		**26.34 €**	**31.36 €**	**37.14 €**



	PEB building A	PEB building B	nZEB building C
high	42.51	35.33	37.14
medium	35.81	29.59	31.36
low	29.73	24.37	26.34

high medium low

Chart 4.1 Total cost calculated for each building [€/m2*y]

By "pricing" the categories listed in Table 4.1 (see Chart 4.1) it is possible to associate a cost of:

- 29.73 to 42.51 €/m^2*y, for building A,
- 24.37 to 35.33 €/m^2*y, for building B,
- 26.34 to 37.14 €/m^2*y, for building C.

This implies that, according to all cost estimations, PEB building A is about 12% to 14% "more costly" than nZEB building C, the reference case, while PEB building B always performs better the nZEB building C, i.e. it is about 5% to 7% "less costly". The absolute-value difference across building "costs" provides the direct costing evaluations of the co-benefits. These are, using low-cost estimates:

- 3.40 €/m^2*y in the case of PEB building A (which is more costly than nZEB building C and therefore originates in fact negative co-benefits),
- -1.97 €/m^2*y in the case of PEB building B (which is less costly than nZEB building C and therefore originates positive co-benefits).

and using high-cost estimates:

- 5.37 €/m^2*y in the case of PEB building A (which is more costly than nZEB building C and therefore originates in fact negative co-benefits),

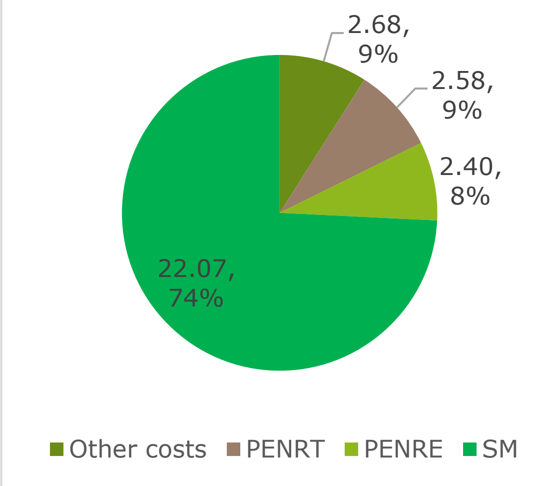
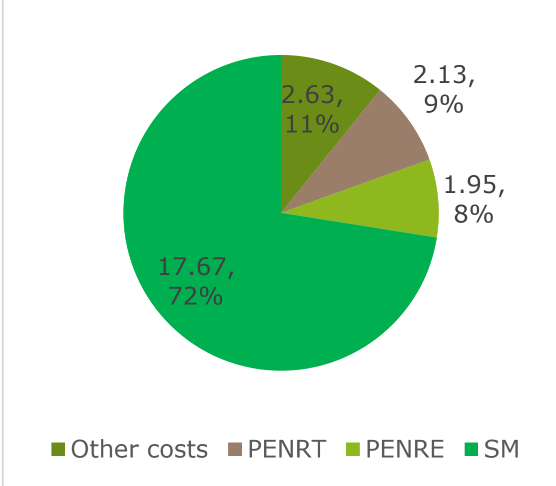
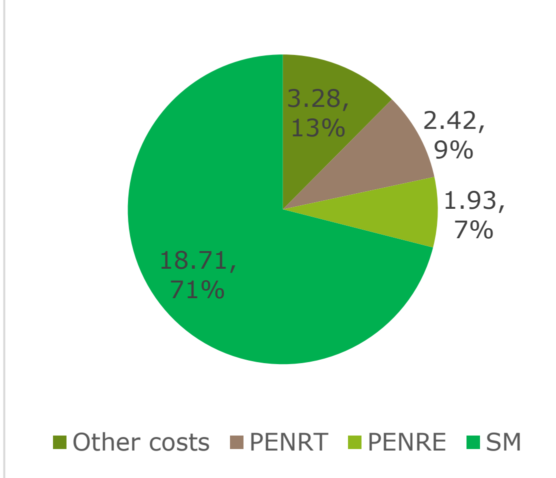
- - 1.81 €/m^2*y in the case of PEB building B (which is less costly than nZEB building C and therefore originates positive co-benefits).

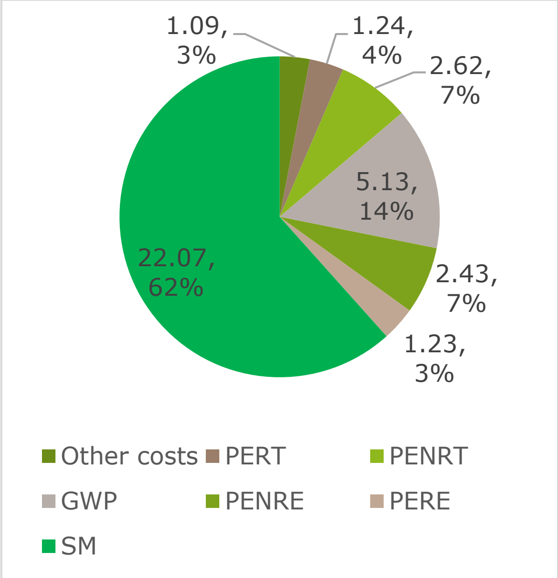
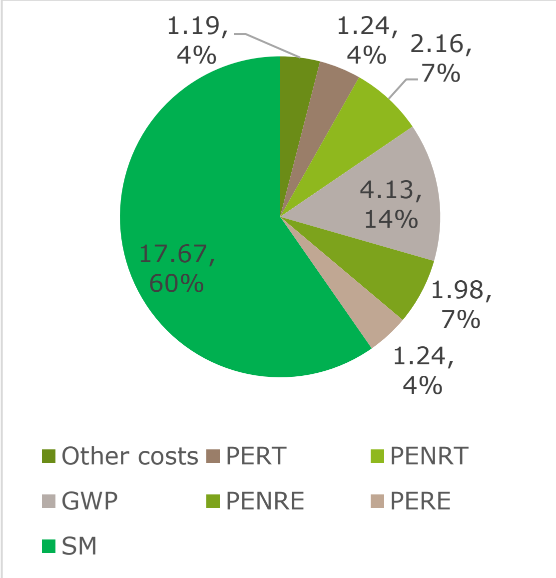
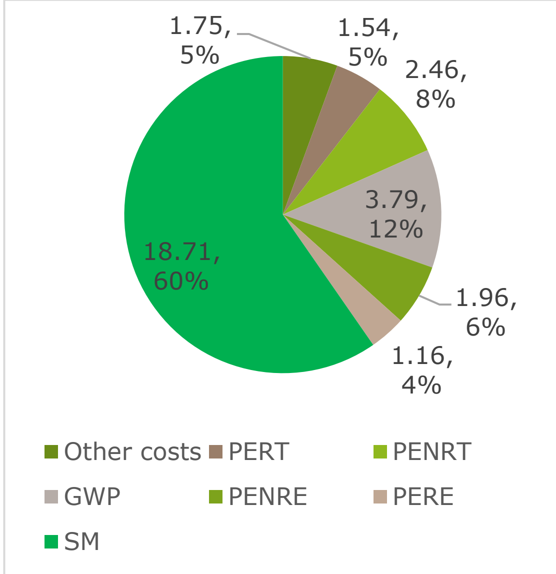
Decomposing the determinants of this result, it can be noted (Table 2) that the higher unit costs, which also present high spread between low and high unit costs estimates, are associated to the emissions of ozone depleting substances (ODP), to the acidification potential (AP) and to the abiotic depletion potential generated by the use of non-fossil resources (ADPE). The largest spread between low and high unit cost estimates are demonstrated by Eutrophication potential (EP).

However, the final determination of co-benefits also depends on the emitted/used quantity of the single substances. Therefore, compounding cost measures with quantity data, it emerges that (Chart 4.2), in the low-cost case, co benefits are mostly associated with the three categories of: input of secondary material (SM), total use of non-renewable primary energy resource (PENRT), non-renewable primary energy as energy carrier (PENRE). Also, in the high-cost case input of secondary material (SM) emerges as the largest contributor to the co-benefit determination. This is then followed by global warming potential (GWP), non-renewable primary energy as energy carrier (PENRE), total use of non-renewable primary energy resource (PENRT), total use of renewable primary energy resources (PERT), renewable primary energy as energy carrier (PERE), and abiotic depletion potential for fossil resources (ADPF).

Focusing on the single indicators, enables to describe with more detail the contribution to co-benefits of the PEB buildings with respect to nZEB building C (Chart 4.3):

- PEB building A performs better than the reference case in 11 out of 24 co-benefit indicators: PERT, ODP, POCP, MER, MFR, NHWD, FW, PERM, PENRM, EEE, EET;
- PEB building B outperforms the reference case in 15 out of 24 indicators: PERT, PENRT, ODP, EP, POCP, ADPF, MER, MFR, NHWD, FW, SM, PERM, PENRM, EEE, EET.

	PEB building A	PEB building B	nZEB building C
LOW			

MEDIUM			
MEDIUM			

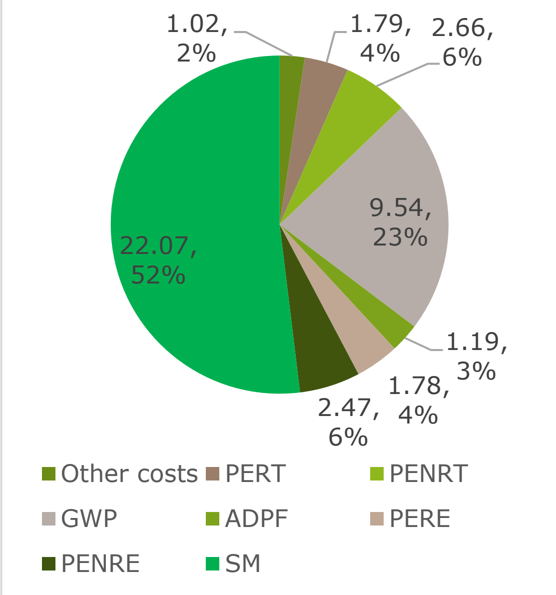
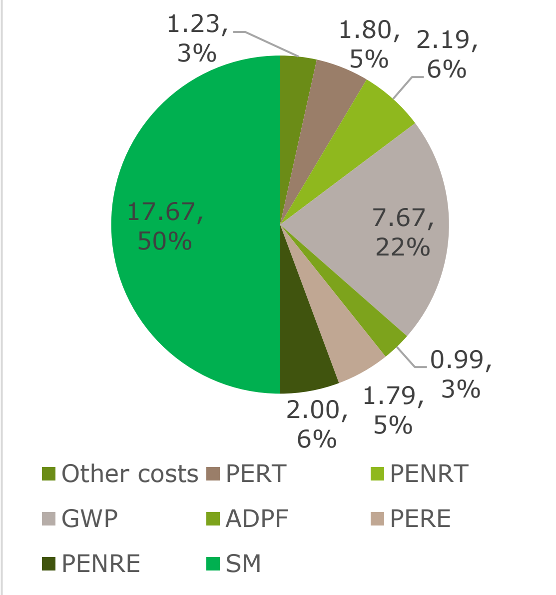
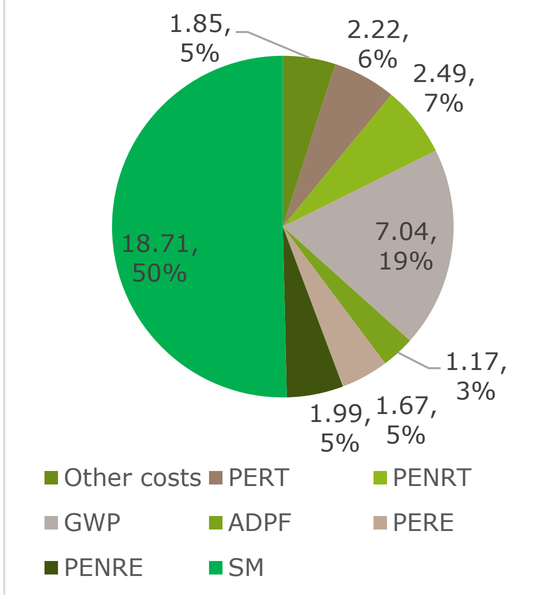
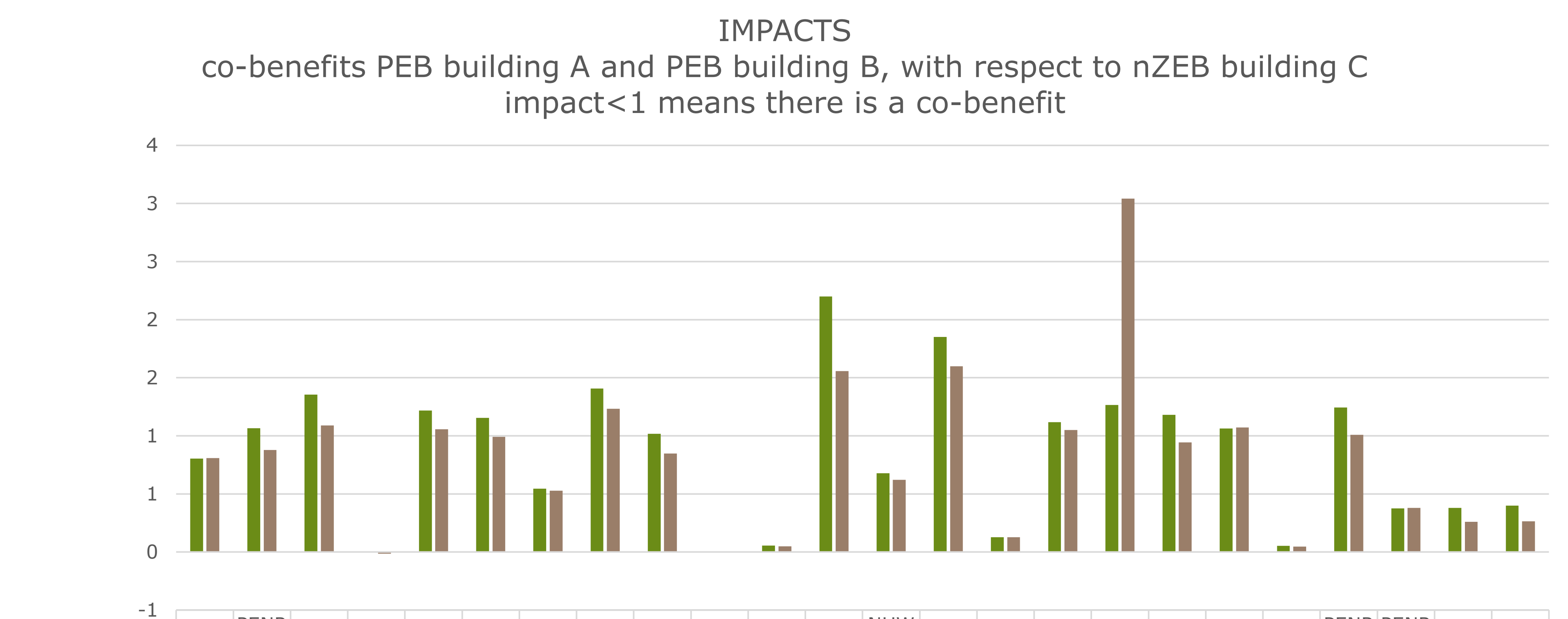
HIGH			
			

Chart 4.2 Cost shares associated with different co-benefit indicators for each building in the low, medium, high costs cases [€]



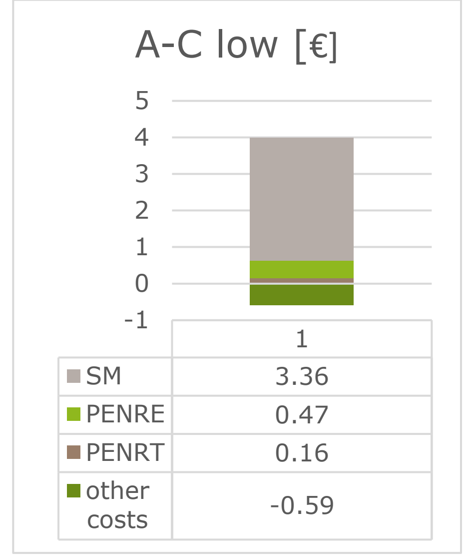
	PERT	PENRT	GWP	ODP	AP	EP	POCP	ADPE	ADPF	MER	MFR	RWD	NHWD	HWD	FW	NRSF	RSF	SM	PERE	PERM	PENRE	PENRM	EEE	EET
A/C impacts	0.80	1.07	1.36	0.00	1.22	1.15	0.55	1.41	1.02	0.00	0.06	2.20	0.68	1.85	0.13	1.12	1.27	1.18	1.06	0.05	1.24	0.38	0.38	0.40
B/C impacts	0.81	0.88	1.09	-0.02	1.06	0.99	0.53	1.23	0.85	0.00	0.05	1.56	0.62	1.60	0.13	1.05	3.04	0.94	1.07	0.05	1.01	0.38	0.26	0.26

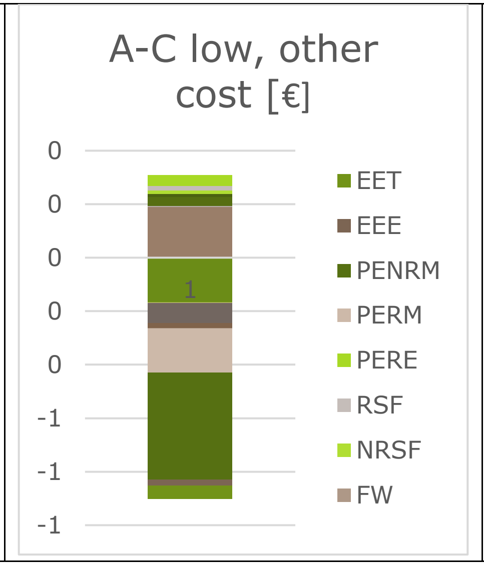
Chart 4.3 In-depth comparison across the three buildings.

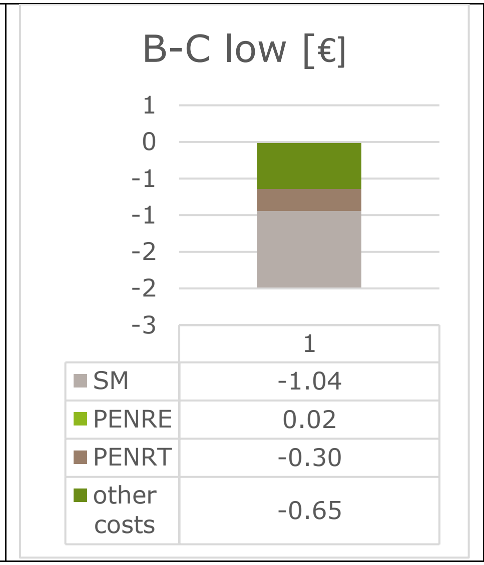
The worse aggregated performance of PEB building A compared with the reference nZEB building C (Chart 4.4), is always mostly due to the higher costs associated with use of secondary material (SM), Non-renewable primary energy as energy carrier (PENRE), Total use of non-renewable primary energy resource (PENRT). When the medium-cost estimates are used, in addition Renewable primary energy as energy carrier (PERE) and global warming potential (GWP) become a relevant source of co-benefit loss; and when the high-cost estimates are used, in addition Abiotic depletion potential for fossil resources (ADPF) becomes a relevant source of co-benefit loss. These cost items build about 80% of the (negative) co-benefits of A (for low, medium high costs).

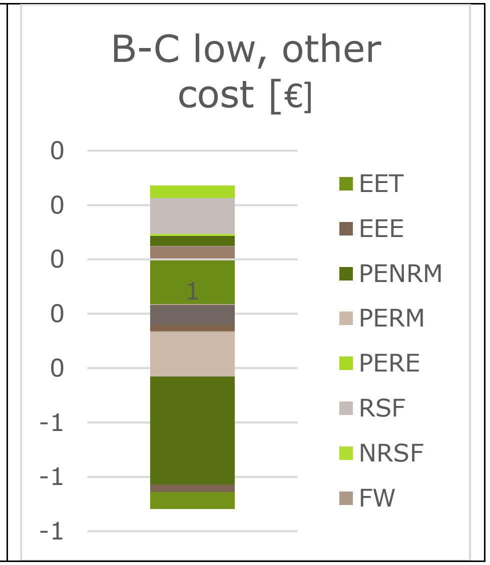
Considering the total co-benefits associated with all the items the nZEB reference building C outperforms the PEB building A by 3.4 and 5.4 €/m^2*y in the low and high-cost cases respectively.

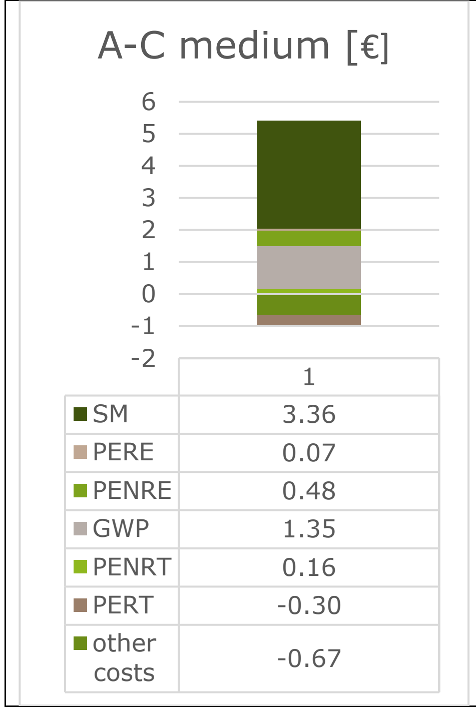
The aggregated performance of PEB building B is always better than that of the nZEB reference building C independently upon the cost estimates used: PEB building B outperforms nZEB reference building C by 2 and by 1.8 €/m^2*y in the low and high-cost cases respectively.

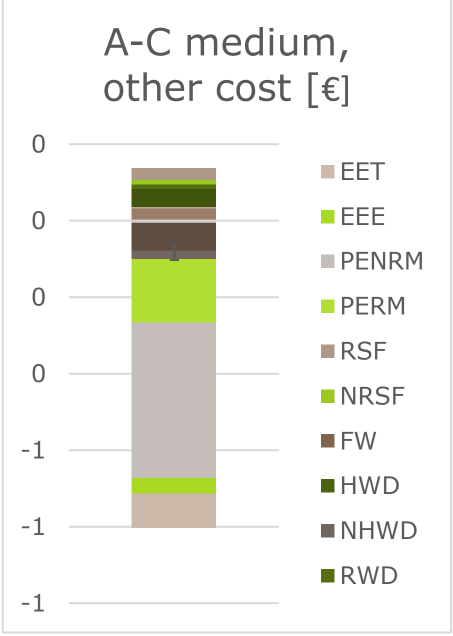

A-C low [€]
5
4
3
2
1
0
-1
1
SM 3.36
PENRE 0.47
PENRT 0.16
other costs -0.59

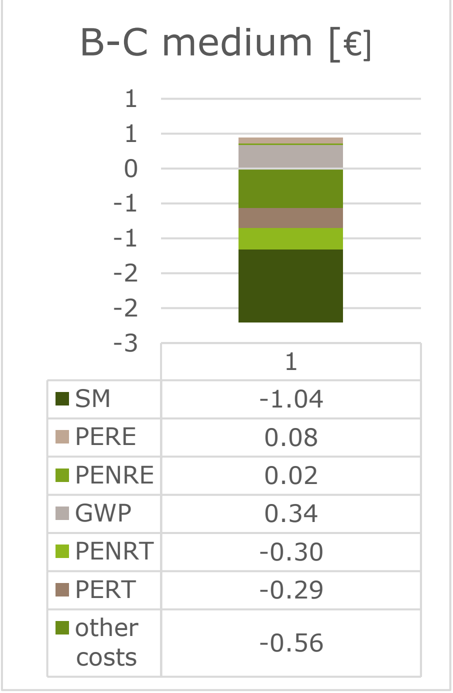

A-C low, other cost [€]
0
0
0
0
0
-1
-1
-1
1
EET
EEE
PENRM
PERM
PERE
RSF
NRSF
FW

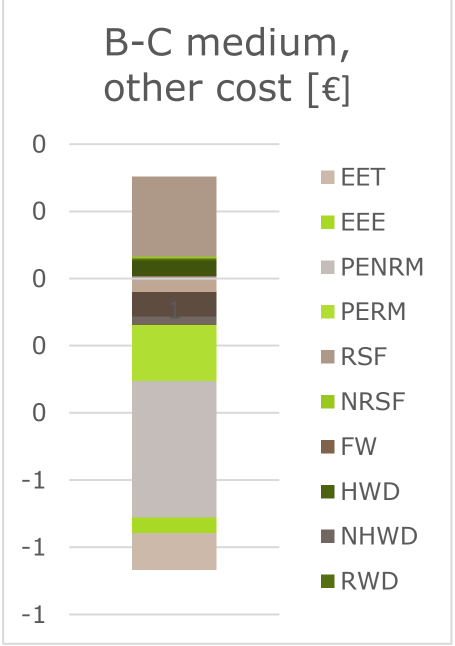

B-C low [€]
1
0
-1
-1
-2
-2
-3
1
SM -1.04
PENRE 0.02
PENRT -0.30
other costs -0.65

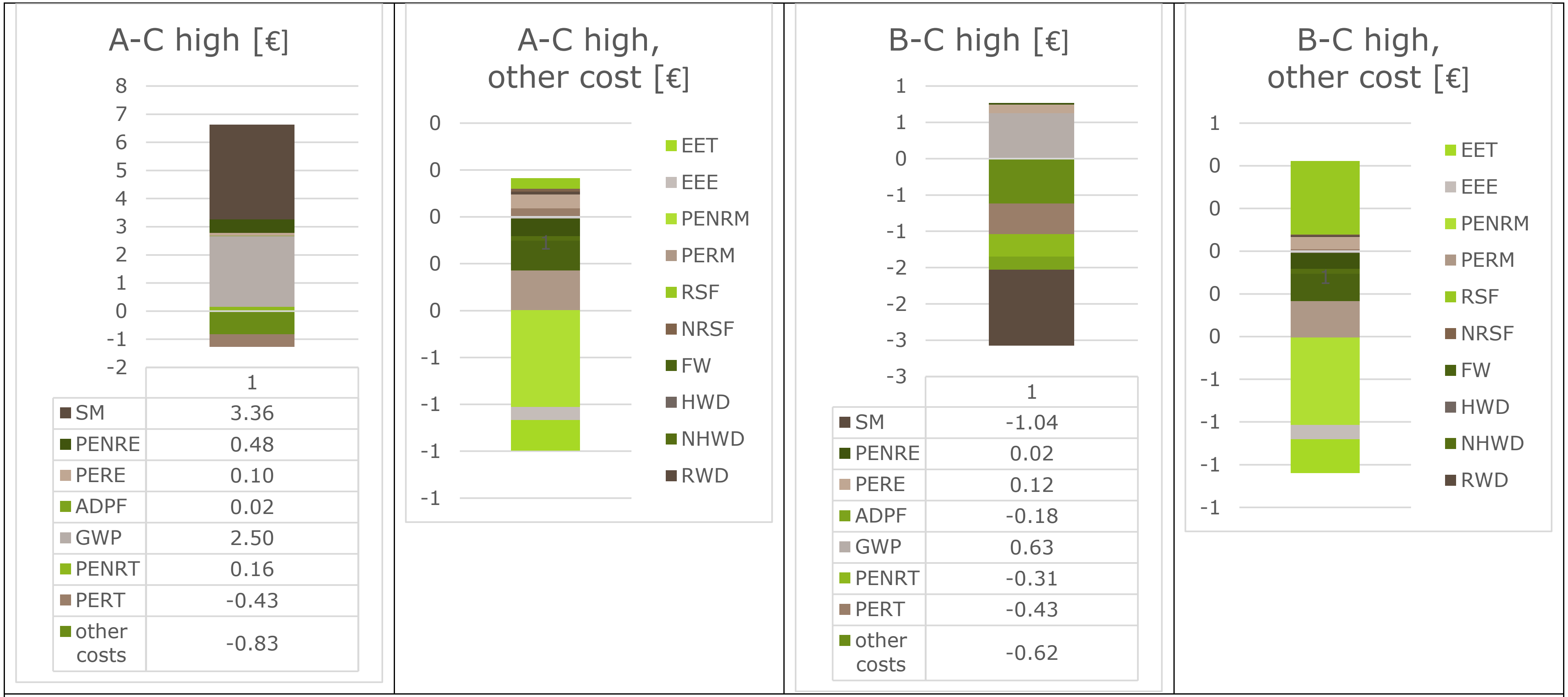

B-C low, other cost [€]
0
0
0
0
0
-1
-1
-1
1
EET
EEE
PENRM
PERM
PERE
RSF
NRSF
FW


A-C medium [€]
6
5
4
3
2
1
0
-1
-2
1
SM 3.36
PERE 0.07
PENRE 0.48
GWP 1.35
PENRT 0.16
PERT -0.30
other costs -0.67


A-C medium, other cost [€]
0
0
0
0
-1
-1
-1
1
EET
EEE
PENRM
PERM
RSF
NRSF
FW
HWD
NHWD
RWD


B-C medium [€]
1
1
0
-1
-1
-2
-2
-3
1
SM -1.04
PERE 0.08
PENRE 0.02
GWP 0.34
PENRT -0.30
PERT -0.29
other costs -0.56


B-C medium, other cost [€]
0
0
0
0
0
-1
-1
-1
1
EET
EEE
PENRM
PERM
RSF
NRSF
FW
HWD
NHWD
RWD



A-C high	1
SM	3.36
PENRE	0.48
PERE	0.10
ADPF	0.02
GWP	2.50
PENRT	0.16
PERT	-0.43
other costs	-0.83

B-C high	1
SM	-1.04
PENRE	0.02
PERE	0.12
ADPF	-0.18
GWP	0.63
PENRT	-0.31
PERT	-0.43
other costs	-0.62

Chart 4.4 Contribution to performance in absolute values [€]

CONCLUSIONS

The direct costing co-benefit assessment emphasized that the two typologies of PEB considered may, in fact, originate either higher or lower total co-benefits than the nZEB reference. However, looking into the determinants of this result, it also emerges that both the PEB buildings A and B are always superior to the reference in some categories of co benefit indicators. Namely:

- Total use of renewable primary energy resources (PERT)
- Non-renewable primary energy as material utilization (PENRM)
- Exported electrical energy (EEE)
- Exported thermal energy (EET)
- Depletion potential of the stratospheric ozone layer (ODP)
- Formation potential of tropospheric ozone photochemical oxidants (POCP)
- Material for Energy Recovery (MER)
- Materials for recycling (MFR)
- Non-hazardous waste dispose (NHWD)
- Use of net fresh water (FW)
- Primary energy resources used as raw materials (PERM).

The fact that in other categories the reference could be superior to the PEB, and that net effects could be favourable to the former, hint that the major gains related to PEBs indeed reside in their energy generation potential rather than in markedly superior or more efficient building characteristics.

This outcome however needs some important qualifications:

- Independently upon the net outcome, PEB buildings A and B in fact outperform nZEB reference building C in several cost categories. Nonetheless, the co-benefits stemming from these categories are associated with a lower economic value than other categories.
- In relation to this, it has to be considered that the monetary evaluation of co-benefits is uncertain. For many cost categories, the cost spread between lower and upper values is huge with the latter more than 1000 times larger than the former. This can highly influence the assessment. This is particularly evident when the use of freshwater is considered. The choice of its pricing determines whether PEB B generates positive co-benefits or not.
- The performance of the PEB buildings A and B respect to the reference nZEB building C in the single indicator types can be used to guide the design of PEB buildings towards improving their co-benefits.

- Finally, it has to be considered that in the present assessment, not all the categories potentially origin of co-benefits has been evaluated.

4.1.4 The German case study

DESCRIPTION

The building types that are contrasted are representative of the German context. The buildings chosen have the following characteristics, as described in Cultural-E D6.3 (Leis and di Bari, 2023):

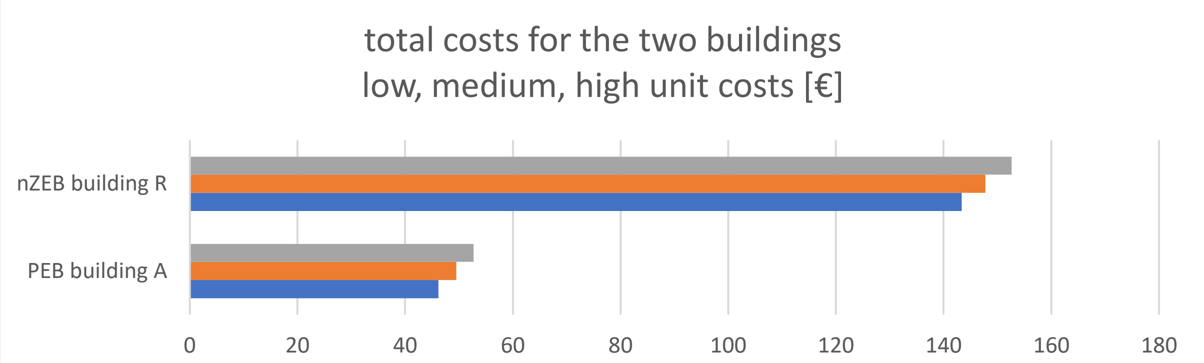
- PEB Building A consists of: 4 above ground floors and one basement level. The ground floor accommodates 560 m2 of commercial use, whereas the top three floors contain 21 rental apartments with a usable area of 1570 m2, all equipped with balconies and terraces. Approx. 40 parking places will be provided in the basement. The total gross building area is 4125 m2 including the basement level. The total building height is 13 m. The structure is a wood/concrete hybrid: the basement level and building core housing the vertical circulation is designed in reinforced concrete, whereas the remaining load-bearing structure above ground is envisioned in wood. The roof provides approx. 550 m^2 of area for the installation of PV-panels.
- nZEB Building C. This is the reference case. In accordance with the Cultural-E consortium decision it is a nZEB. It consists of: 4 floors, total floor area of 2363 m^2, net floor area 1986 m^2. The structure is mixed, primarily reinforced concrete. It has a decentralized ventilation, floor heating, centralized heating with a condensing boiler, and lift.

RESULTS

Table 4.4 reports extensively the calculation done, while Charts 4.5 to 4.8 visualize the results of the procedure.

Table 4.4. Calculation of costs, German case study (€)

	PEB Building A				nZEB Building C			
Indicator	**impact/m²*y**	**A – low**	**A - medium**	**A – high**	**impact/m²*y**	**C - low**	**C – medium**	**C – high**
PERT	93.81	1.69 €	3.04 €	4.39 €	28.45	0.51 €	0.92 €	1.33 €
PENRT	21.19	0.29 €	0.29 €	0.30 €	116.36	1.59 €	1.62 €	1.64 €
GWP	3.84	0.15 €	1.08 €	2.01 €	13.31	0.53 €	3.76 €	6.99 €
ODP	0.00	0.00 €	0.00 €	0.00 €	0.00	0.00 €	0.00 €	0.00 €
AP	0.02	0.01 €	0.10 €	0.11 €	0.02	0.01 €	0.12 €	0.13 €
EP	0.00	0.00 €	0.01 €	0.01 €	0.00	0.00 €	0.01 €	0.01 €
POCP	0.00	0.00 €	0.01 €	0.01 €	0.01	0.00 €	0.01 €	0.01 €
ADPE	0.00	0.00 €	0.00 €	0.00 €	0.00	0.00 €	0.00 €	0.00 €
ADPF	35.67	0.00 €	0.05 €	0.24 €	109.81	0.00 €	0.14 €	0.75 €
MER	5.75	-1.81 €	-2.48 €	-3.16 €	0.06	-0.02 €	-0.03 €	-0.03 €
MFR	9.54	26.99 €	26.99 €	26.99 €	45.59	128.98 €	128.98 €	128.98 €
RWD	0.00	-0.02 €	-0.02 €	-0.02 €	0.00	0.01 €	0.01 €	0.01 €
NHWD	8.20	0.26 €	0.26 €	0.26 €	24.77	0.78 €	0.78 €	0.78 €
HWD	0.00	0.00 €	0.00 €	0.00 €	0.00	0.00 €	0.00 €	0.00 €
FW	-0.68	0.00 €	0.00 €	-0.16 €	0.04	0.00 €	0.00 €	0.01 €
NRSF	1.01	0.01 €	0.01 €	0.01 €	0.49	0.01 €	0.01 €	0.01 €
RSF	7.05	0.13 €	0.23 €	0.33 €	0.12	0.00 €	0.00 €	0.01 €
SM	5.74	16.23 €	16.23 €	16.23 €	3.06	8.66 €	8.66 €	8.66 €
PERE	90.70	1.63 €	2.94 €	4.24 €	25.27	0.45 €	0.82 €	1.18 €
PERM	1.78	0.02 €	0.02 €	0.03 €	3.13	0.04 €	0.04 €	0.04 €
PENRE	24.14	0.33 €	0.34 €	0.34 €	106.85	1.46 €	1.49 €	1.51 €
PENRM	3.64	0.05 €	0.05 €	0.05 €	8.38	0.11 €	0.12 €	0.12 €
EEE	2.93	0.05 €	0.09 €	0.14 €	3.05	0.05 €	0.10 €	0.14 €
EET	6.74	0.12 €	0.22 €	0.32 €	7.08	0.13 €	0.23 €	0.33 €
TOTAL		**46.15 €**	**49.46 €**	**52.67 €**		**143.35 €**	**147.79 €**	**152.61 €**



	PEB building A	nZEB building R
high	52,67	152,61
medium	49,46	147,79
low	46,15	143,35

Chart 4.5 Total cost calculated for each building [€/m2*y]

By "pricing" the categories listed in Table 1 (see Chart 4.5) it is possible to associate a cost of:

- 46.1 to 52.7 €/m^2*y, to PEB building A,
- 143.3 to 152.6 €/m^2*y, to nZEB building C.

This implies that PEB building A is 65 to 68% cheaper (in terms of co-damages production, the dual of co-benefit) than the reference. The absolute-value difference across building "costs" provides the direct costing evaluations of the co-benefits. These are positive and total:

- 97.2 €/m^2*y using "low-cost estimates".
- 99.9 €/m^2*y using "high-cost estimates".

Decomposing the determinants of this result, it can be noted (Table 2a) that the higher unit costs are associated to the emissions of ozone depleting substances, the disposal of non-hazardous wastes and to the abiotic depletion potential generated by the use of non-fossil resources. The largest spread between low and high-cost estimates are demonstrated by the use of freshwater, the abiotic depletion from fossil and non-fossil resources, the global warming potential and acidification. However, the final determination of co-benefits also depends on the emitted/used quantity of the single substances. Therefore, compounding cost with quantity data, it emerges that (Table 2b and Chart 4.6) co benefits are dominated by materials for recycling and input of secondary materials. The latter, in particular, builds the bulk of the difference across the German PEB and nZEB showing much better performance of the first building type.

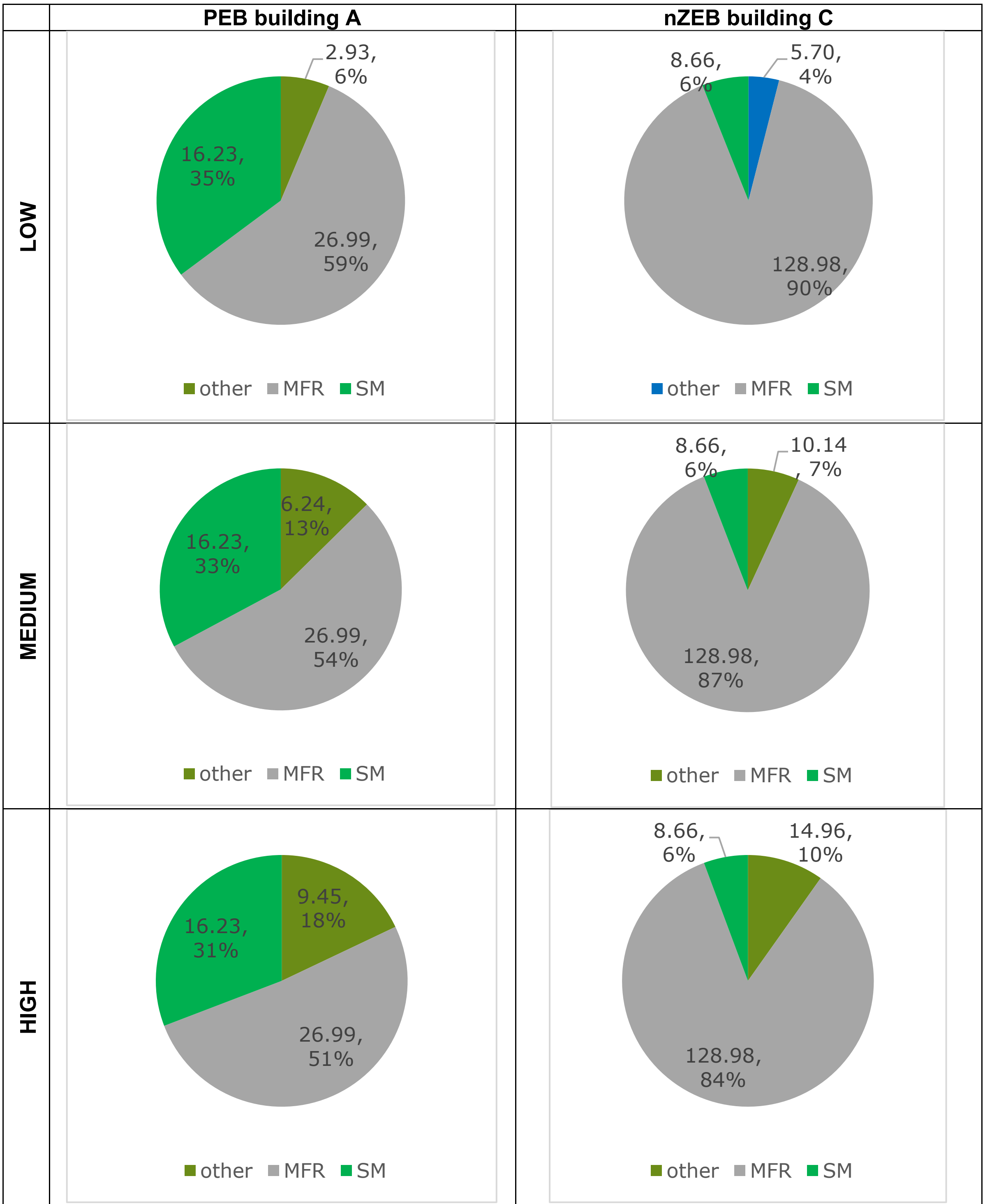


Chart 4.6 Cost shares associated to different co-benefit indicators for each building for low, medium, high costs [€]

Focusing on the single indicators, enables to describe with more detail the contribution to co-benefits of the PEB building A with respect to nZEB building C (Chart 4.7):

- PEB building A performs better than the reference case in 15 out of 21 co-benefit indicators: PENRT, GWP, ODP, AP, EP, POCP, ADPF, MFR, RWD, NHWD, PERM, PENRE, PENRM, EEE, EET;

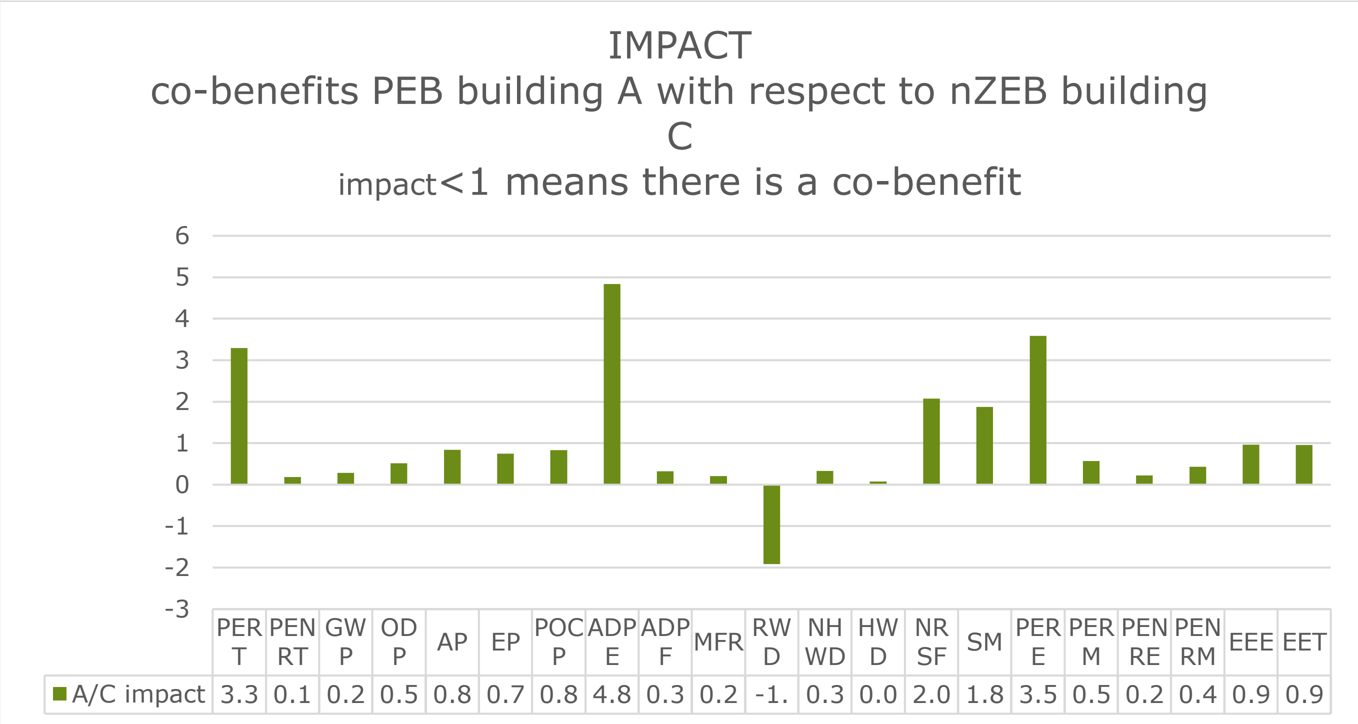
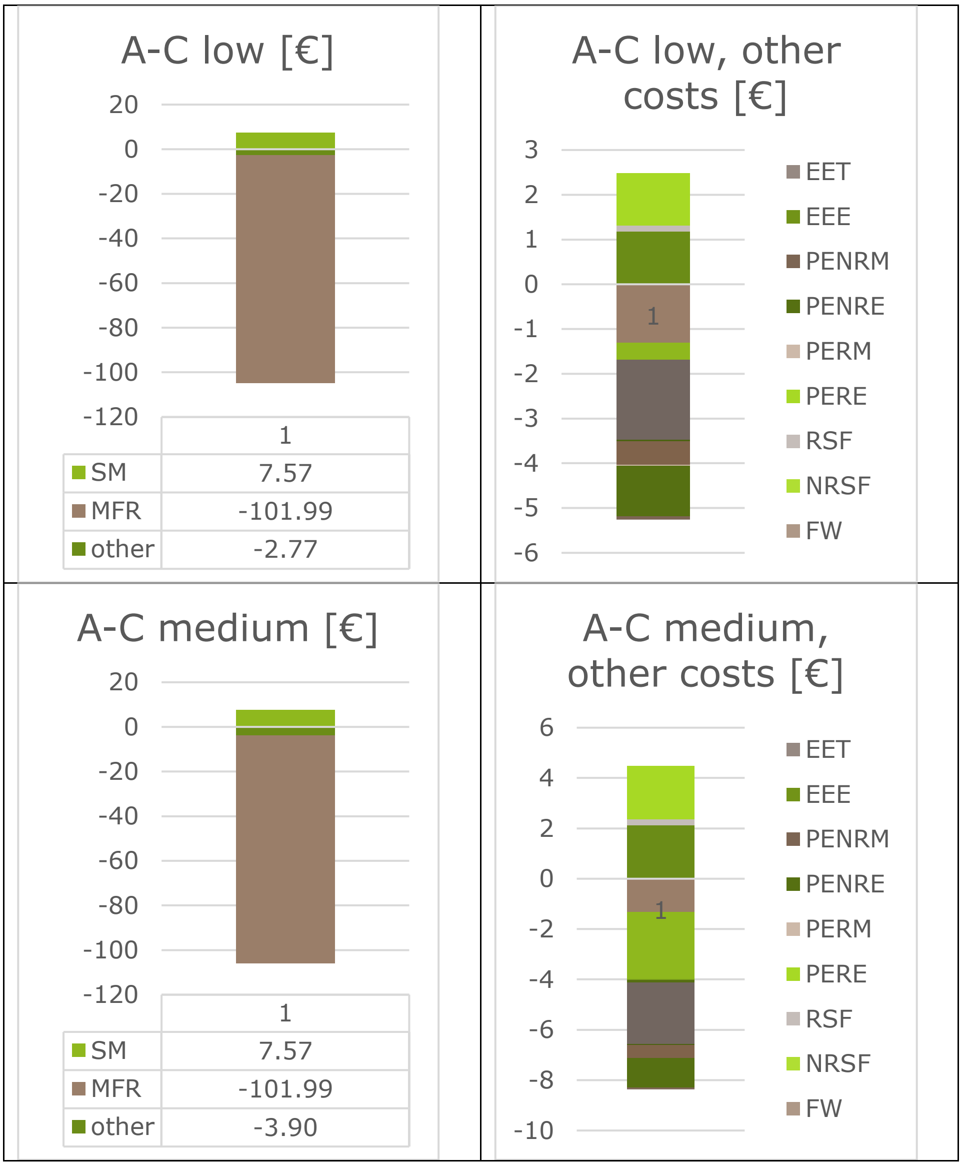


Chart 4.7 In-depth comparison across the two buildings.

As mentioned, the best aggregated performance of the PEB building A compared with the reference nZEB building C, is almost entirely due to the lower costs associated with material for recycling (MFR) (see Chart 4.8). On the contrary, examining the use of secondary materials (SM), the use of renewable resources as energy carriers (PERE), the use of renewable primary energy resources (PERT) and the use of renewables secondary fuels (RSF) the nZEB reference slightly outperforms the PEB. However, the lower co-benefits associated with these items are much smaller that the positive co-benefits from material for recycling. Altogether they build a co benefit value of roughly 2.5 to 6 €/m^2*y against more than 100 €/m^2*y deriving from the material from recycling.


A-C low [€]
20
0
-20
-40
-60
-80
-100
-120
1
SM 7.57
MFR -101.99
other -2.77
A-C low, other costs [€]
3
2
1
0
-1
-2
-3
-4
-5
-6
EET
EEE
PENRM
PENRE
PERM
PERE
RSF
NRSF
FW
A-C medium [€]
20
0
-20
-40
-60
-80
-100
-120
1
SM 7.57
MFR -101.99
other -3.90
A-C medium, other costs [€]
6
4
2
0
-2
-4
-6
-8
-10
EET
EEE
PENRM
PENRE
PERM
PERE
RSF
NRSF
FW

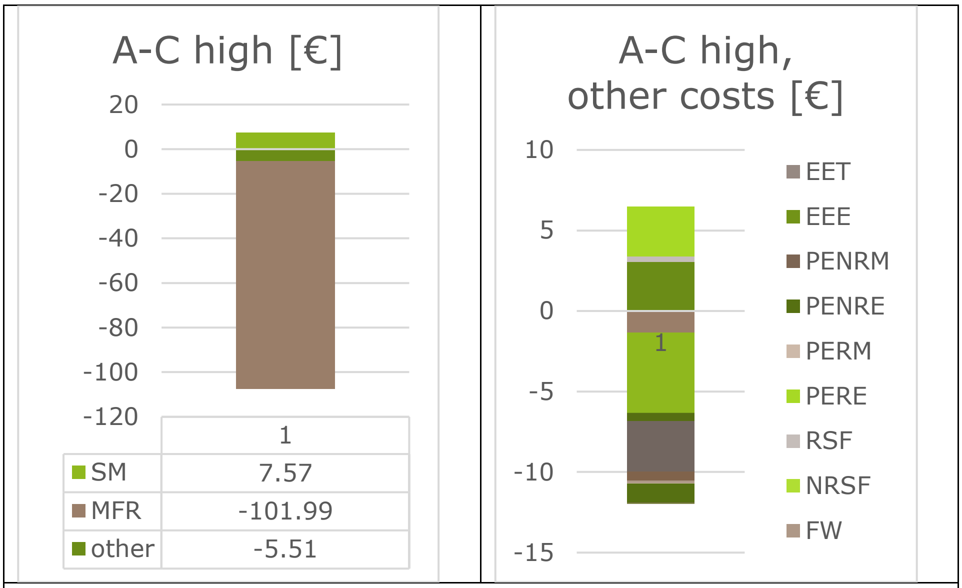


Chart 4.8 Contribution to co benefit performance in absolute values [€]

CONCLUSIONS

The direct costing co-benefit assessment emphasized that, in the German case, the PEB considered may, in fact, originate substantively positive net co-benefits compared with the nZEB reference. This is an additional advantage on top of its energy generation potential.

This outcome however needs some important qualifications:

- Independently upon the net outcome, the nZEB in fact outperforms the PEB in several cost categories, most notably the use of secondary materials. The co benefits stemming from these categories are however associated with a lower economic value than the other categories.
- The monetary evaluation of co-benefits is uncertain. For many cost categories, the cost spread between lower and upper values is huge with the latter more than 1000 times larger than the former. This can highly influence the assessment. In the specific German case study however, this variability is less of an issue given that the largest spread in cost assessment is linked with the use of freshwater resources that is limited in both types of buildings.
- Finally, it has to be considered that in the present assessment, not all the categories, which are potentially origin of co-benefits, have been evaluated.

4.1.5 The French case study

DESCRIPTION

The demo case selected for the Oceanic climate is derived from a theoretical case study in Leers (France), close to the Belgian border. The theoretical demo is a private social housing. Building A is targeted to be the Cultural-E PEB demonstrator. Building B, with a very similar design, is planned as an nZEB building (Passive house). The two buildings are identical unless the installation of PV modules, which is foreseen in the PEB.

The buildings consist of:

- 19 appartements
- 4 floors
- Balcony
- Total living space: 1110m²
- 9 x T2 appartements (≈48m²)
- 10 x T3 appartements (≈67m²)
- Roof area 280m²

The structural system is made of reinforced concrete elements. Designers have not specified other elements. Different constructive scenarios have been realised to cover such data gaps, each representing a building part (foundation, external wall, internal walls, ceilings, roof, technical installation). For the building elements of the envelope, systems with U-value according to national regulations are considered. Such systems are also derived from GENERIS® software and the Fraunhofer IBP database, which collects construction systems that are consistent with the building praxis of the Central Europe region.

The following systems are considered:

- 2 foundation systems
- 3 external walls systems
- 1 interior wall system
- 2 ceilings systems
- 6 roof options
- 1 solution set of technological installation according to the one conceived in the Cultural-E activities. In this solution set, 6 scenarios of energy production via PV installations are considered
- 4 scenarios of energy demand with different user profiles according to the analyses provided by Nobatek.

These scenarios are combined, and 2304 buildings' combinations are derived. 288 are consistent with the nZEB building (no PV installed); 2016 there were PEBs.

In the two groups of combinations, the ones with higher environmental advantages in terms of GWP and better energy performance are selected. These interestingly correspond to buildings with identical envelopes and construction systems, in the following described.

- The derived buildings have foundations lying on the soil. The basement is covered with screed and PE foil for sealing. A multi-layer timber cover is applied.
- External walls are made of reinforced concrete structural elements and Cellulose fibre insulation. Lime gypsum plaster and facing bricks are applied as covering elements. PVC doors and Eurofinestra Active Window Systems are used for the openings.
- Interior walls are made of aerated concrete elements, and wood fibre panels are installed through a dry process for areas that need thermal and acoustics insulations. Lime gypsum plaster and interior paint are applied for covering. Wood doors are used.
- Ceiling elements have reinforced concrete structural elements, Calcium sulphate screed (anhydrite flowing screed), Lime gypsum interior plaster and interior paint for covering. A multi-layer parquet is foreseen, except for the bathrooms with glazed stoneware tiles.
- Roof elements have reinforced concrete elements, PU insulation panels with a mineral fleece top layer, gravel on the outer surface and Lime gypsum interior plaster with Interior paint inside. Bitumen membrane and Thermoplastic polyethene are used for roofing and vapour barrier. The optimal photovoltaic system for the PEB has a 200 m² surface (whole roof area). Energy demand scenarios with righteous users and minimal energy consumption are preferred.

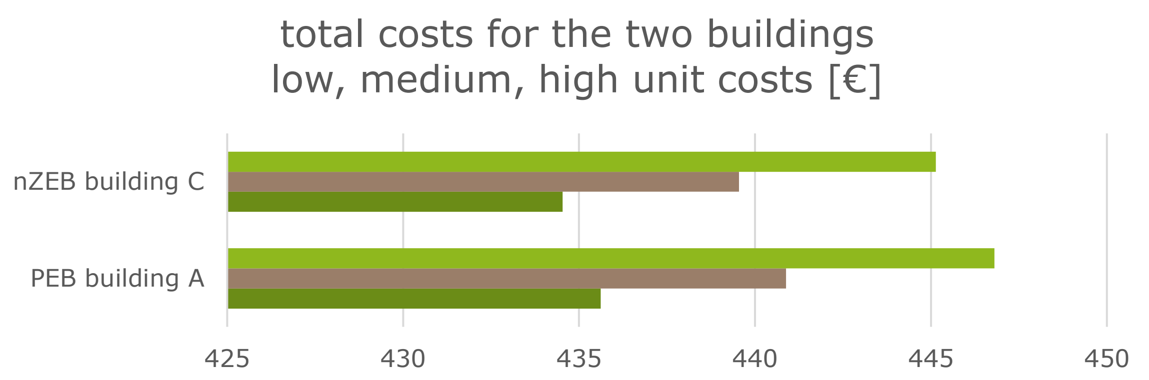
For these building systems, the co-benefits are evaluated.

RESULTS

Table 4. 5 reports extensively the calculation done, while Charts 4.9 to 4.12 visualize the results of the procedure.

Table 4. 5. Calculation of costs, French case study (€)

	PEB Building A				nZEB Building C			
Indicator	**impact/m²*y**	**A – low**	**A - medium**	**A – high**	**impact/m²*y**	**C - low**	**C – medium**	**C – high**
PERT	52.54	0.95 €	1.70 €	2.46 €	46.88	0.84 €	1.52 €	2.19 €
PENRT	122.42	1.68 €	1.70 €	1.73 €	100.94	1.38 €	1.40 €	1.42 €
GWP	13.01	0.52 €	3.68 €	6.83 €	12.87	0.51 €	3.63 €	6.75 €
ODP	0.00	0.00 €	0.00 €	0.00 €	0.00	0.00 €	0.00 €	0.00 €
AP	0.03	0.01 €	0.14 €	0.16 €	0.02	0.01 €	0.11 €	0.13 €
EP	0.00	0.00 €	0.01 €	0.01 €	0.00	0.00 €	0.01 €	0.01 €
POCP	0.00	0.00 €	0.00 €	0.01 €	0.00	0.00 €	0.00 €	0.01 €
ADPE	0.00	0.00 €	0.00 €	0.00 €	0.00	0.00 €	0.00 €	0.00 €
ADPF	114.28	0.00 €	0.15 €	0.78 €	95.59	0.00 €	0.12 €	0.65 €
MER	1.39	-0.44 €	-0.60 €	-0.76 €	1.39	-0.44 €	-0.60 €	-0.76 €
MFR	74.78	211.57 €	211.57 €	211.57 €	74.68	211.30 €	211.30 €	211.30 €
RWD	0.00	0.02 €	0.02 €	0.02 €	0.00	0.01 €	0.01 €	0.01 €
NHWD	5.81	0.18 €	0.18 €	0.18 €	5.56	0.18 €	0.18 €	0.18 €
HWD	0.00	0.00 €	0.00 €	0.00 €	0.00	0.00 €	0.00 €	0.00 €
FW	1.22	0.01 €	0.01 €	0.29 €	1.21	0.01 €	0.01 €	0.29 €
NRSF	11.24	0.15 €	0.16 €	0.16 €	11.24	0.15 €	0.16 €	0.16 €
RSF	23.96	0.43 €	0.78 €	1.12 €	23.96	0.43 €	0.78 €	1.12 €
SM	76.97	217.79 €	217.79 €	217.79 €	76.97	217.79 €	217.79 €	217.79 €
PERE	52.12	0.94 €	1.69 €	2.44 €	46.46	0.84 €	1.51 €	2.17 €
PERM	0.47	0.01 €	0.01 €	0.01 €	0.47	0.01 €	0.01 €	0.01 €
PENRE	122.09	1.67 €	1.70 €	1.72 €	100.61	1.38 €	1.40 €	1.42 €
PENRM	0.95	0.01 €	0.01 €	0.01 €	0.95	0.01 €	0.01 €	0.01 €
EEE	1.85	0.03 €	0.06 €	0.09 €	1.79	0.03 €	0.06 €	0.08 €
EET	4.29	0.08 €	0.14 €	0.20 €	4.14	0.07 €	0.13 €	0.19 €
TOTAL		435.62 €	440.89 €	446.80 €		434.53 €	439.54 €	445.14 €



	PEB building A	nZEB building C
high	446.80	445.14
medium	440.89	439.54
low	435.62	434.53

Chart 4.9 Total cost calculated for each building [€/m2*y]

By "pricing" the categories listed in Table 1 (see Chart 4.9) it is possible to associate a cost of:

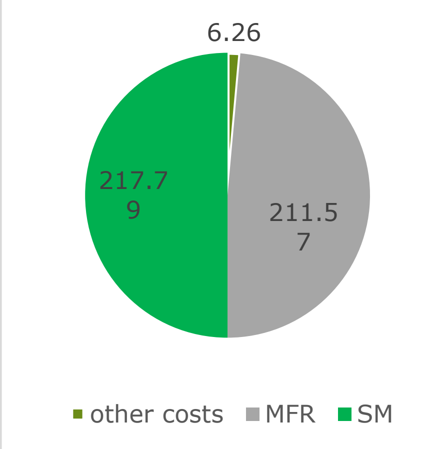
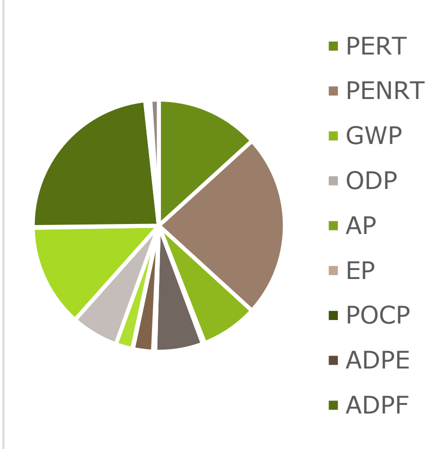
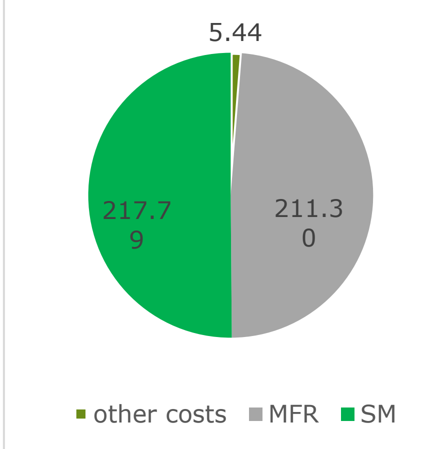
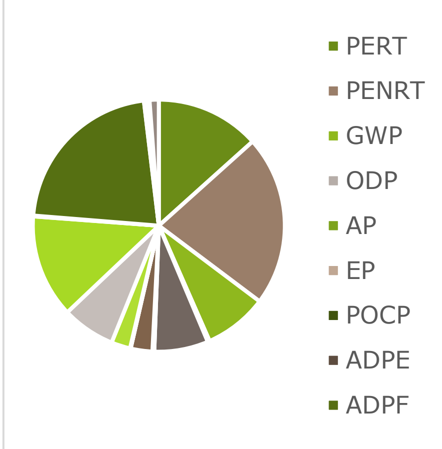
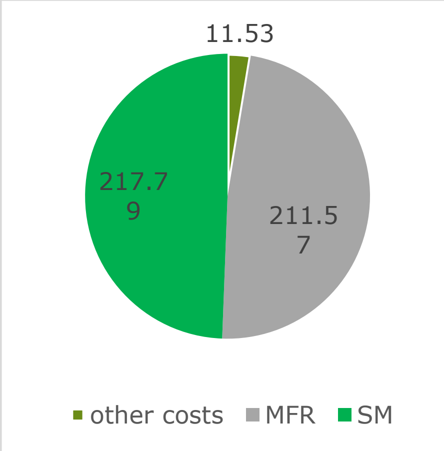
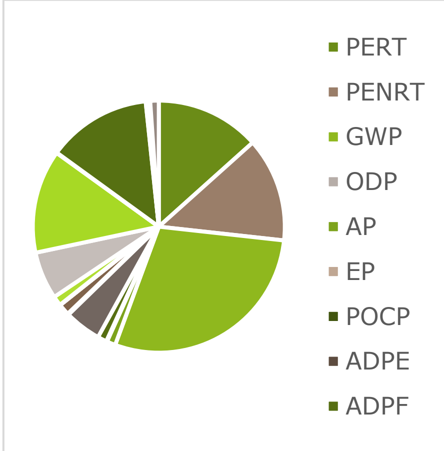
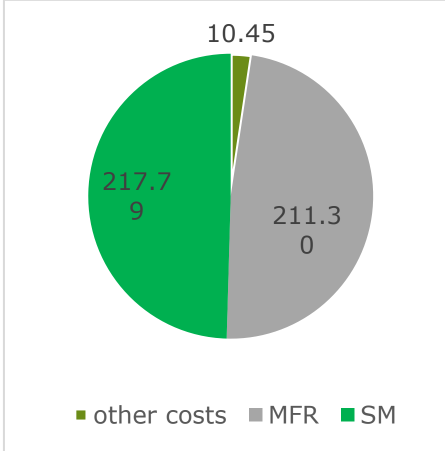
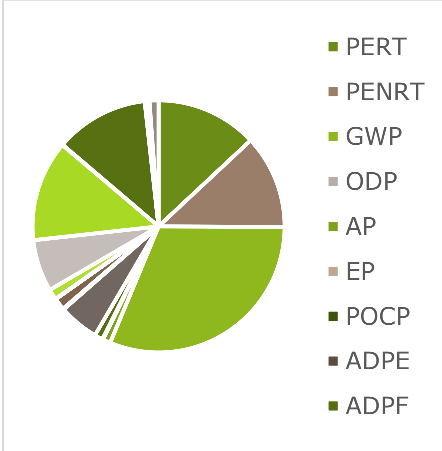
- 435.62 to 446.80 €/m^{2}*y, to PEB building A,
- 434.53 to 445.14 €/m^{2}*y, to nZEB building C.

This implies that nZEB building C is about 0.5% cheaper for all cost estimates (in terms of co-damages production, the dual of co-benefit) than the PEB building A. The absolute-value difference across building "costs" provides the direct costing evaluations of the co-benefits. These are positive and total:

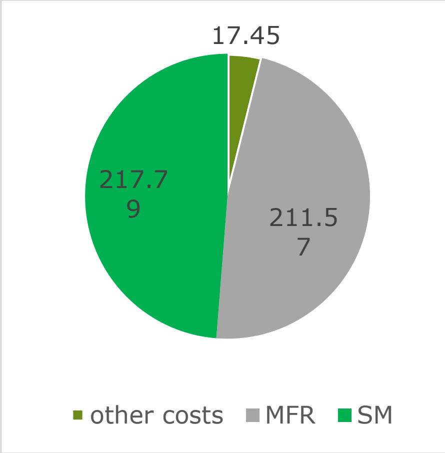
- 1.08 €/m^{2}*y using "low-cost estimates".
- 1.66 €/m^{2}*y using "high-cost estimates".

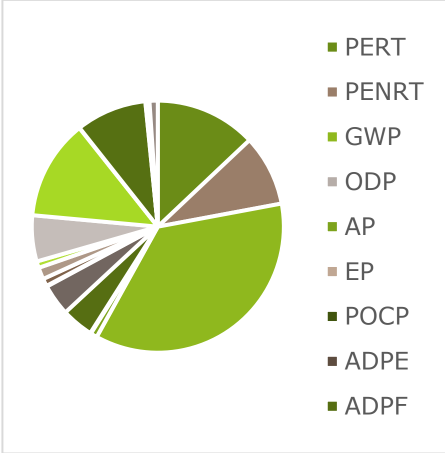
Decomposing the determinants of this result, it can be noted (Table 2a) that the higher unit costs are associated to the emissions of ozone depleting substances, the disposal of non-hazardous wastes and to the abiotic depletion potential generated by the use of non-fossil resources. The largest spread between low and high-cost estimates are demonstrated by the use of freshwater, the abiotic depletion from fossil and non-fossil resources, the global warming potential and acidification. However, the final determination of co-benefits also depends on the emitted/used quantity of the single substances. Therefore, compounding cost with quantity data, it emerges that (Table 2b and Chart 4.10) co-benefits are dominated by Materials for recycling (MFR) and Input of secondary material (SM).

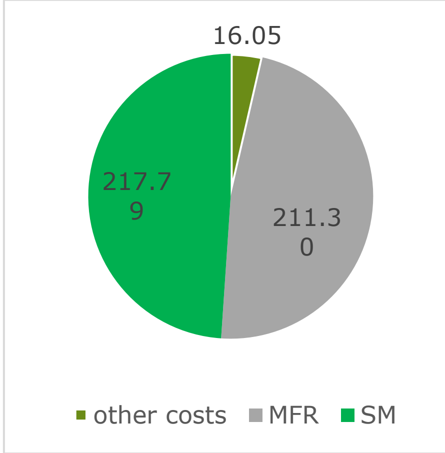
However, the relative co-benefits are not dominated by any indicator, because the final costs calculated for both buildings are very similar: the net co-benefit is always equal to or lower than 0.30 EUR.

	PEB building A	PEB building A – other costs	nZEB building C	nZEB building C – other costs
LOW				
MEDIUM				

HIGH







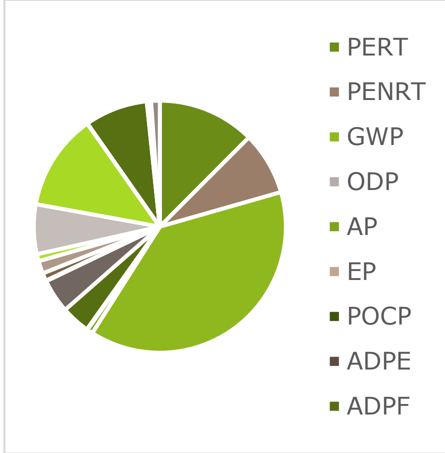


Chart 4.10 Cost shares associated to different co-benefit indicators for each building for low, medium, high costs [€]

Focusing on the single indicators, enables to describe with more detail the contribution to co-benefits of the PEB building A with respect to nZEB building C (Chart 4.11):

- PEB building A performs equal to the reference nZEB building C in 8 out of 24 co-benefit indicators: ODP, MER, MFR, NRSF, RSF, SM, PERM, PENRM,
- for all other indicators nZEB building C performs better.

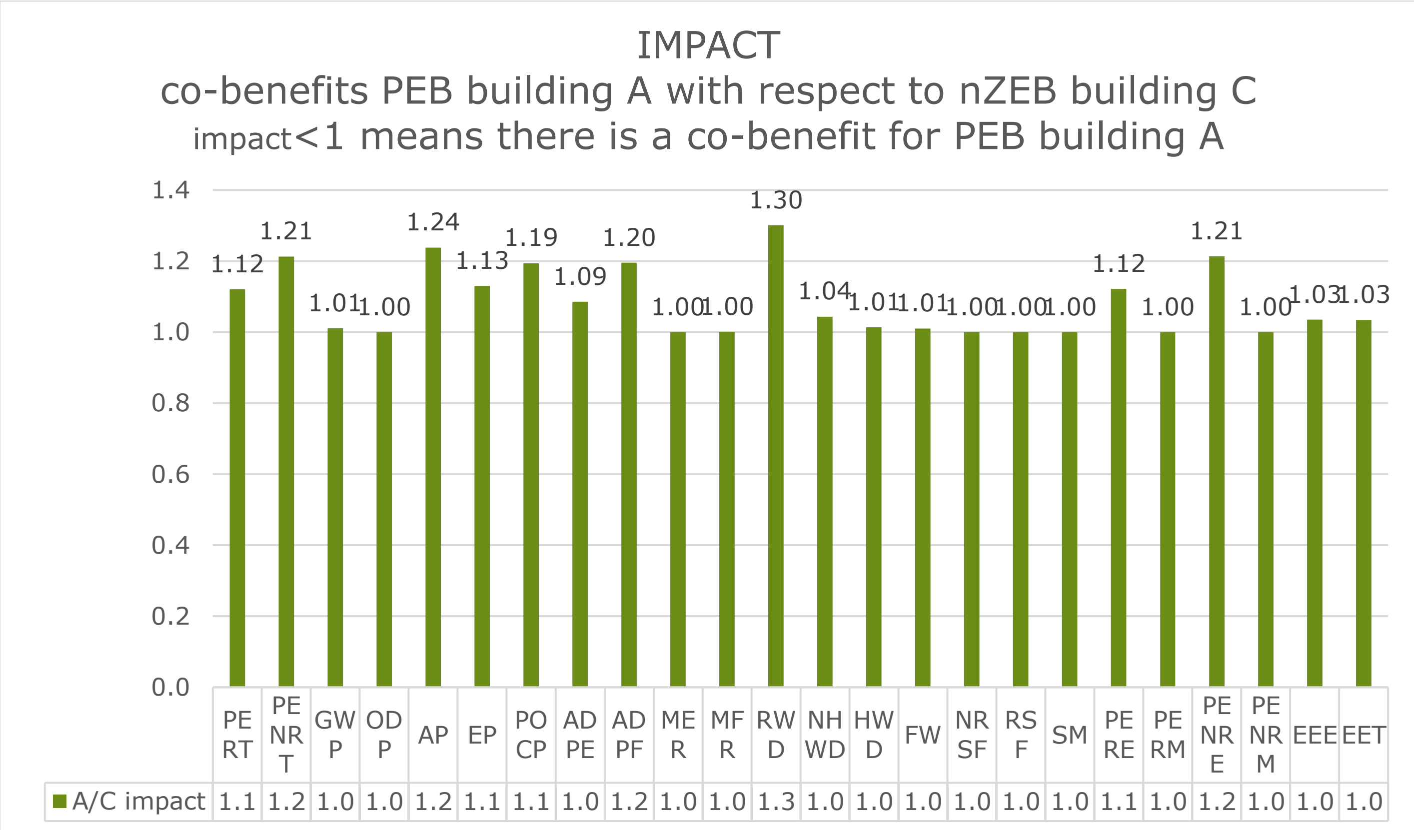


Chart 4.11 In-depth comparison across the two buildings.

Looking at the co-benefits' performance in absolute values (Chart 4.12), 5 indicators contribute the most: PERT, PENRT, MFR, PERE, PENRE.

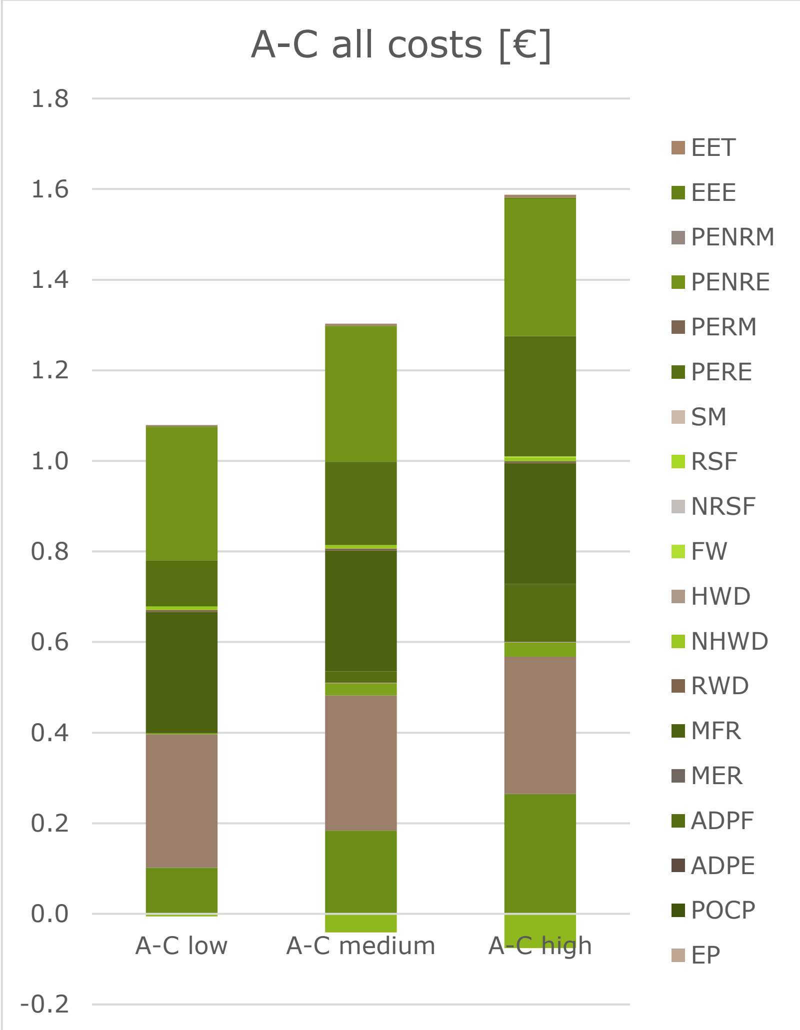


Chart 4.12 Contribution to co benefit performance in absolute values [€]

CONCLUSIONS

The direct costing co-benefit assessment emphasized that, in the French case, the PEB demo and the nZEB reference provide almost identical results. Therefore, there is only a tangible benefit, i.e., the energy generation potential.

4.2 Results for the stated preference evaluation

4.2.1 Empirical analysis: Study Design - Valuation Task

We selected six attributes for inclusion in our hypothetical scenarios, namely

- connection to a Positive Energy District (PED) (present or absent)
- number of expected outages of the approximate duration of 2 hours each (total 4 categories)
- centralized air filtration system (present or absent)
- centralized mechanical ventilation system (present or absent)
- sensors and app to optimize electric appliances (present or absent)
- sensors and app to optimize energy use for heating and cooling while keeping thermal comfort (present or absent

We created all possible scenario combinations based on the above listed attributes (there are 4 x 2 x 2 x 2 x 2 x 2 = 2^6 = 128 possible scenario combinations) and selected seven of them a random for a total of 24 times, forming a total of 24 different variants of the valuation exercise. The respondents were to be assigned at random to one of these 24 variants. In each of the seven valuation scenarios, the respondent was to indicate whether under this scenario the rental value of their home would stay the same or change, and, if the latter, by how much. In the part of survey questionnaire (described in the next sub-section) devoted to value elicitation, respondents were to enter such rental value changes expressed in euro per month.

4.2.2 Empirical analysis: Study Design – Survey Questionnaire

The questionnaire opens with a few questions to ensure that sampling quotas are fulfilled. We ask about gender, age and place of residence (by means of a search field coupled with a scroll down menu showing all municipalities belonging to the areas of interest for this study).

Next, we ask about the respondents' neighbourhood, in terms of degree of urbanization and the overall "vibe" of the neighbourhood (that is, whether it is getting more popular or unpopular, more expensive or cheaper). We then inquire about the dwelling in general (type, size, rooms, age of the building and time of occupancy) and about its energy-related features: the dwelling's energy efficiency labels (the one at the time of the purchase and the current one), energy use (in terms of systems, fuels, and appliances used for space heating and cooling, water heating, and cooking), the presence of thermostats and smart meters, the presence of factors enabling prosumer behaviour, such as PV panels, small wind turbines, electricity storage and participation in net metering and in positive energy districts, as well any subsidy received for domestic electricity generation. We also ask about any energy efficiency or structural renovations that were carried out, and when this happened.

We then narrow or focus on co-benefits, starting with a qualitative assessment of the level of satisfaction of the respondents with thermal comfort in winter and in summer, air quality (indoors and outdoors), noise, light, air filtration and ventilation, the value-for-the-money of the house's thermal comfort in ration to energy bills, and exposure to electric outages.

We set up our value elicitation by asking how much the respondent thinks a home exactly like theirs and at this location would rent for in today's home rental market in their municipality. To help the respondents come up with realistic values, we program into the questionnaire an automated check that computes the minimum and maximum monthly rental price of a housing unit of the same size and location of the respondent's dwelling, drawing on a detailed database of current rental prices per square meter in France and Germany at the NUTS3 level[6] and the size of the dwelling provided by the respondent. If respondents enter a value that is too high or too low for the area where they live, a follow-up question offers the opportunity to correct or confirm the rental price provided.

We then ask respondents to evaluate seven alternative hypothetical configurations of a dwelling, described in terms of different levels of attributes portraying the co-benefits listed in Section 2.1 (see Table 4.6). An example of the resulting evaluation card used in the survey is shown in Figure 4.1.

Attribute	**Levels**
Number of expected outages per year (of the expected duration of 2 hours each)	0 OR 1-2 OR 3-5 OR 6-7
Positive Energy District participation	Connected OR not connected
Ventilation	Available OR not available
Filtration	Available OR not available

[6] Data on average, minimum and maximum rental prices were recovered, respectively from the Deutschland Atlas and Mietspiegel Deutschland for Germany and from Seloger for France. The first source is a statistical data platform of German government; the other two are private real estate services platforms covering the whole national territories of the two countries and providing specific reports for provinces and main cities.

App and sensors for indoor thermal comfort	Available OR not available
App and sensors for optimal appliances' use	Available OR not available

Table 4.6. Attributes and levels in the evaluation task

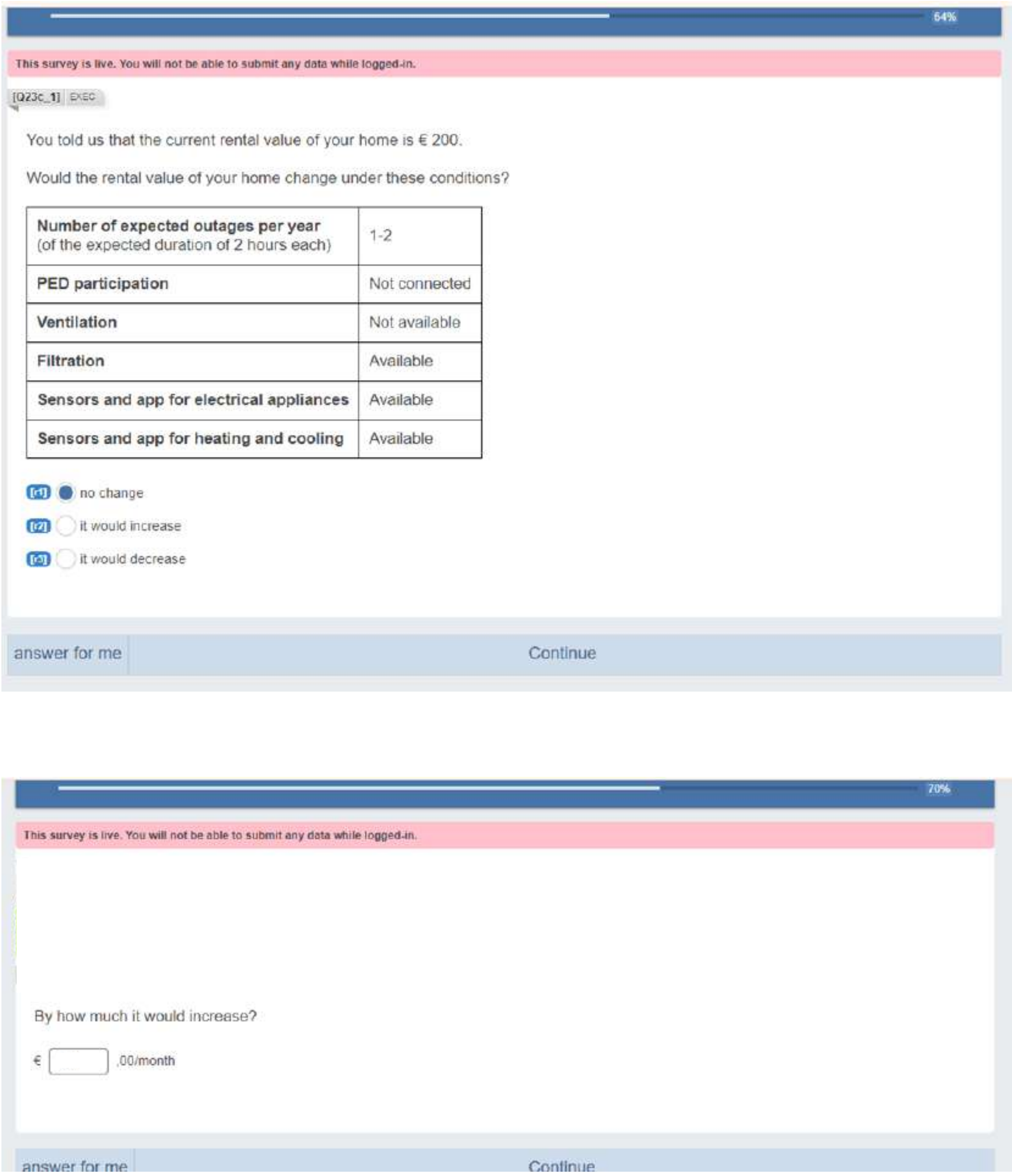


Figure 4.1. Evaluation task as displayed in the online survey questionnaire.

We complement this evaluation exercise with a direct elicitation of the value of joining a PED. This elicitation is framed in terms of Willingness to Accept (WTA), for people that have micro-generation installed at home (PVs or small wind turbines) and in terms of WTP for those who do not have such technologies installed. The exercise is performed in two steps: first we ask if an amount randomly selected between 50, 100, 250, 500, 1000 Euro would be acceptable and would trigger participation into such network; then we ask which would be the amount (minimum compensation for net energy providers and maximum contribution for net energy users) that would trigger such participation[7].

The last section of the questionnaire covers the usual socio-demographics, with the addition of two debriefing questions about their previous experience with the topic of the survey: We ask them if they are, or have been landlords renting out dwellings (and hence having a more accurate knowledge of the rental housing market); and if they have been working in sectors related to energy, energy efficiency, building and construction, real estate, public administration and policy making.

The final questionnaire was written in English to have an unambiguous common reference. Once finalised, this master questionnaire was translated into French and Germany and proofread by native speakers. The survey was soft launched on a restricted sample of 100 respondents per country on September 18th, 2024. Once verified that everything was proceeding as expected, the full survey was launched in the field, one week later. Data collection was completed on October 1st, 2024, and the final dataset was delivered to the research team the following day.

4.2.3 Empirical analysis: Models

The key outcome variable in this study is the change in rental value announced by the respondent for each of the seven hypothetical situations they are asked to consider. We fit the linear regression model:

(1) $$\Delta R_{ij} = \mathbf{X}_{ij}\boldsymbol{\beta} + \mathbf{Z}_i\boldsymbol{\gamma} + \varepsilon_{ij}$$

where *i* denotes the respondent, *j* denotes the "choice card" (j=1, 2, …, 7), **X** is a vector of descriptors of the network, expected outages, and equipment described in the hypothetical scenarios, and **Z** is a vector of home, homeowner, neighbourhood and general area characteristics. ε is a zero-mean error term. Importantly, we suppress the constant term, as the change with respect to the current rental value should be brought

[7] The final questionnaire was programmed into Dynata's online platform and carefully tested to make sure that respondents would see the questionnaire exactly as the research team intended: some questions are supposed to be asked only to respondents who selected some specific options in previous questions, and other respondents would find them odd. For instance, the questions on the willingness to participate in a Positive Energy District, are not intended for people already participating in a such a network.

exclusively by the changing conditions surrounding the home in each hypothetical scenario.

We wish to emphasize that **X** contains two PED variables—a dummy denoting its presence or absence on the premises, plus an interaction between no PED and an indicator that the respondent already participates in a PED as a supplier. This is to allow for the possibility respondents who already participate in a PED view the absence of a PED as a "demotion" in the quality of their home.

In principle, the value of some of the hypothetical attributes may be modified by another attribute or by dwelling, homeowner or neighbourhood characteristics. For example, the availability of a PED may be viewed as more attractive if the home is completely dependent on electricity for its energy needs (e.g., heating is electric, which would make the home unpleasantly cold in the event of extended outages during the winter), if the hypothetical scenario entails more numerous outages, and/or if the respondent in real life experiences frequent outages. These considerations suggest that we should enter in the model interactions between PED and indicators of such circumstances, but in early specification searches we found that with these interactions the estimation results were unstable and difficult to interpret. In the remainder of this paper, we thus report the results of specifications where we enter attributes **X** and home, respondent and neighbourhood characteristics **Z** additively.

Our questionnaire uses more than one approach to elicit information about the value of a PED. In addition to capturing the effect of PED participation on the dwelling's rental value, we also ask those respondents who are not currently signed up with a PED to tell us whether they would be willing to participate in one if it cost them €B a year. We also ask persons with PVs whether they would be willing to participate in a PED as a supplier of electricity if they received a compensation of €C a year. The responses to these questions can be used to estimate the mean (median) WTP and mean (median) WTA for a PED.

We assume that the underlying WTP for a PED is normally distributed with mean μ and variance σ^2. A respondent will thus agree to an annual cost of €B if their WTP is greater than €B. Formally,

(2) $$\Pr(yes|B) = \Pr(\mu + \varepsilon_i > B_i) = \Phi(\alpha + \beta \cdot B_i)$$

where $\alpha = \mu/\sigma$ and $\beta = -1/\sigma$. Equation (2) is a probit model where *B*, which is varied at random across respondents, has been added as an independent variable. One should thus expect the estimated coefficient on B to be negative, which confirms the intuitive expectation that the higher the cost of participating in a PED is, the fewer people should be willing to do it. Mean (median) WTP is estimated as $\hat{\mu} = -\hat{\alpha}/\hat{\beta}$, where $\hat{\alpha}$ is the intercept in the probit model and $\hat{\beta}$ is the coefficient on the proposed cost amount. The standard error around the mean WTP is obtained using the delta method.

Similar methods can be applied to obtain estimates of the mean and median WTA from homeowners with PVs. The only difference is that the coefficient on variable *C*, the proposed compensation, which we vary at random across respondents, should be positive, confirming the intuitive notion that more homeowners can be expected to participate in a PED at higher compensation amounts.

4.2.4 Empirical analysis: Data

We gathered a total of 2051 completed questionnaires, approximately evenly split between the two countries (see Table 3.**3** in Section 3 for our original quota targets and their actual sample shares). Most of our respondents (62.21%) live in single-family homes, but semi-detached homes (9.85%), terraced houses (12.48%), and apartments in multi-family buildings (15.11%) are also present in our sample.

Approximately 35% of the respondents' report using natural gas as their main heating fuel; electricity is the main heating fuel for 30.57% of the sample, heating oil for 15.87%, and wood or pellets for almost one quarter of the sample. About one quarter of the respondents' report having PV solar panels at their premises. This share is larger among the Germans (37.40% v. 13.42%). Out of those equipped with PVs, 32% currently participate in a positive energy district (PED) as a supplier, for an overall share of about 8% of the sample.

The homeowners in our sample had limited experience with power outages lasting 5 minutes or more. One third reported experiencing none whatsoever in the last 12 months, one third about 1-2, and only about 3.5% of the sample said they had experienced 11 or more.

Our respondents were willing and able to estimate the rental value of their homes. Once we drop the bottom and top 1% of these responses, which we judge implausible, the mean monthly rent is 1203 euro (median 1000 euro). Table A3.1 displays the results of a linear regression model that seeks to relate the current rental value to characteristics of the home, the owner, the neighbourhood and the general area. At an R square of about 25%, rental values depend in the expected ways on the type and size of the dwelling, and on the general "vibe" of the neighbourhood. They do not appear to vary with the type of heating fuel used, but they are significantly higher, all else the same, with whether the dwelling has micro-generation equipment. Importantly, respondents who have current or prior experience as landlords reported higher rental values, all else the same, and rental values decline with the length of time someone has lived in their home. It is well documented in the housing economics literature that the ability to estimate property values (or rental values) closely depends on how recent one's housing market experience is (Goodman and Ittner, 1992). What we see here appears to confirm this notion.

The key variable gathered in this questionnaire is, of course, the change in the rental value of the home that the respondents associate with certain well-defined, but hypothetical, changes in the conditions of the dwelling. Figure A3.1 displays the histogram of such changes in rental values. The evidence in. Figure A3.1 is striking: The histogram displays a massive spike at zero, as zero accounts for 65% of the responses, with non-zero rental value changes approximately symmetrical around zero.

Closer inspection of the data reveals that a non-trivial share of the respondents (24%) reported no change in rental value in *all* the seven evaluation tasks they were faced with. We suspect that these respondents were unwilling or unable to engage in the valuation exercise, and we formally explore this conjecture by running probit regressions where the dependent variable is a "always zero respondent" dummy and the independent variables are dwelling, owner, neighbourhood and area characteristics. As shown in Table A3.2, the characteristics of the dwelling do little in terms of explaining the "always zero" cases, and neighbourhood trends are only weakly associated with the "always zero" cases. The likelihood that someone will be an "always zero" respondent is lower among our German subjects and among persons with current or prior landlord experience, and higher among persons who have been living longer at their current address. Having PVs does not influence someone's likelihood of being an "always zero" respondent.

In the remainder of this part of the study, we conservatively assume that the "always zero" respondents were unwilling or unable to participate in the survey's hypothetical valuation tasks, and we remove their responses from the usable sample when we examine and statistically model the hypothetical changes in rental values[8]. As shown in

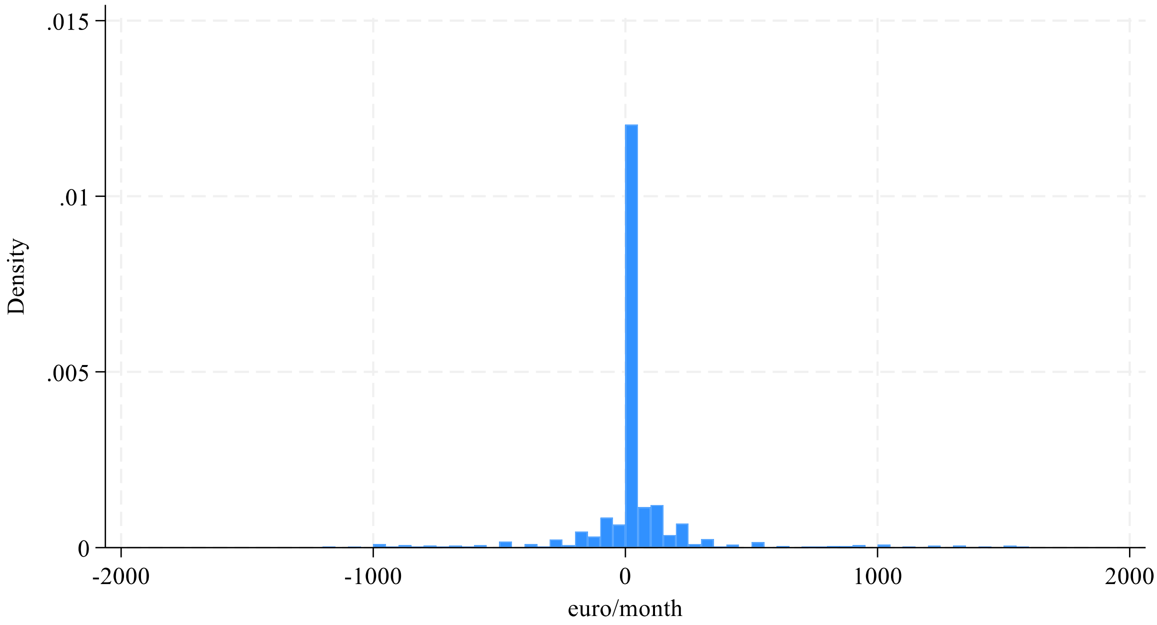


Figure A3.2 even after these subjects are excluded from the sample, the histogram of the rental value changes continues to display a spike at zero, as 56% of the remaining observations are equal to zero.

4.2.3 Empirical analysis: Results

The value of co-benefits: Effect of Energy Enhancements on Rental Values

Table A3.3 shows the results from several specifications of equation (1), where the dependent variable is the change in rental value under each of the seven hypothetical scenarios faced by the respondents. The specification of column (1) enters exclusively the attributes in the scenarios. In column (2) we have added dwelling characteristics, in column (3) characteristics of the owner, and in columns (4) and (5) neighbourhood and area characteristics.

As shown in column (1), getting connected to a PED raises rental values by €38 - €39 a month on average; at the same time, removing the connection to a PED network does not seem to penalize the rental value of homes that already participate in one such network. The rental value of a home decreases monotonically with the expected number

[8] Straight-lining, i.e. respondents give identical answers to items in a battery of questions is a well-known issue in surveys, and researchers can at best hope to minimize it, and mitigate the consequence for the sample by removing identified “straight-liners”. See Kim et al., 2018.

of outages in the scenario: Under the most pessimistic scenario (6-7 outages a year of the duration of 2 hours each), the rental value falls by €146/month.

Our respondents place the same value on an air filtration system and a ventilation system—approximately €40/month—and value a system that optimizes the use of appliances some €51/month. A system that optimises heating and cooling is deemed worth on average €39/month. This suggests to us that these homeowners expect the use of app-controlled sensors to result in savings of at least €51 and €39 per month in the electricity bills and heating/cooling costs, which they hope to be able to partly capture into higher rents.

These results are stable across the specifications, as expected since **X** and **Z** are orthogonal due to the random assignment of the scenarios to the respondents. It is interesting however that home, homeowner, neighbourhood and area characteristics add little to the changes in rental values reported by the respondents. Homes with electric heat are associated with smaller changes (by about €20/month) in rental values under the various scenarios. Neighbourhood trends are only weakly associated with changes in rental values, and having PVs seems to have no effect whatsoever, but there are modest differences across dwelling types.

One important question is whether the various energy enhancement attributes are valued differently across the Germany and France subsample, reflecting different energy cultures as well as different real estate markets. In

Table A3.4 we display the results from fitting separate regressions for each country. The specification is the basic one—that with only the attributes in the scenario and no covariates. Clearly, our German respondents appear to put higher values on PED participation, ventilation and air filtration and appliance and heating/cooling optimization. They also report larger losses of rental values under scenarios that entail outages. However, the French PED participants appear to be more reasonable when they receive a scenario with no PED, in that their rental values do not change, while their German counterparts seem to think that removing the PED connection will raise the rental value. Overall, at an average of €26 versus €9 per month, the German subjects report larger changes in rental value than the French respondents, but a t test indicates that the difference is barely statistically significant at the 5% level (t statistic 1.95).

Table 4.7 below summarizes the value of co-benefits, overall and across the two countries, excluding energy security (PED participation), which is dealt with more in detail in the next subsections. Notice that that these values are expressed in Euro per month. To express them in terms of Euro per square meter per year, they need to be multiplied by 12 and divided by the average size of dwellings in our sample. Since the average size is 171.6 m^2 in Germany, 127.2 m^2 in France and 148 m^2 overall, the values in Table 4.7 below should be multiplied respectively by a factor of 0.07 in Germany, 0.094 in France and 0.08 overall to obtain values in terms of Euro per square meter per year. This would give unit values for co-benefits ranging between € 2.5 per m^2/year in for ventilation France to €4.6 per m^2/year for sensors and apps for appliances in Germany. Note however, that direct estimation in these unit terms was not feasible, as house rental prices are usually best understood for the whole unit, not per square meter.

Co-Benefit	**Germany**	**France**	**Overall**
Environmental Quality – Thermal comfort: Ventilation	54.6	26.5	40.8
Environmental Quality- Air quality: Filtration	49	31.3	40.3
Adaptability: Sensors and apps for appliances	65.8	35.4	51.1
Adaptability: sensors & app for heating/cooling	44	34.7	39

Table 4.7. Co-benefit values, Euro per month.

What is the WTP for PED Participation?

Based on the changes in rental values under the hypothetical scenario, it appears that our survey respondents put a premium on being connected to a positive energy district that ensures an uninterrupted supply of electricity. The annual value of such a connection is €39×12=€468.

Would they announce similar figures if they were asked directly how much they would be prepared to pay for such a connection? We asked the 1544 respondents whose home is not equipped with PVs or other generation devices if they would participate in a PED, and 697 (45.14%) said that they would. We then asked these 697 respondents whether they would be prepared to pay an amount €B chosen at random out of the array {50, 100, 250, 500, 1000}.

Their responses are summarized in Figure A3.3, which shows that the percentage of "yes" responses declines regularly with the €B amount, ranging from 76% when B=€50 to 27% when B=€1000. We fit a simple probit model to these responses, as described in section 3, and display the estimation results in
Table A3.5, column (1). The coefficient on the annual cost is negative and significant, as expected as per statistical model (2), and, when combined with the intercept, results in a mean and median WTP of €440.55 (standard error 38.83), which matches almost exactly the annual value inferred from the rental market responses. Assuming that those

that do not wish to participate in a PED hold a zero WTP amount, the sample-wide mean WTP[9] is €(440.55×0.4514+0×0.5486)=€198.86.

Somewhat surprisingly, the specifications of the probit model displayed in columns (2)-(4) indicate that home, neighbourhood and area characteristics are not associated with someone's WTP for PED participation. The only two factors that seem to be affecting the WTP are nationality (with the Germans holding higher WTP amounts) and current or prior experience as a landlord. The number of outages experienced in the last year does not bear any effect on the WTP either.

5.3. What is the WTA for PED Participation?

Of the 350 respondents who own PVs or other home generation devices, 164 (46.86%) said that they would be willing to participate in a PED as a supplier of electricity.

Figure A3.4 displays the percentage of respondents who would agree to serve as suppliers in one such local network at each of five proposed compensation amounts. Consistent with economic theory and common sense, the share of homeowners who would accept to be part of a PED grows (somewhat slowly) with the proposed compensation amount—from about 35% at €50 per year to 59% at €1000 per year.

The simple model reported in column (1) of Table A3.6 produces an estimated mean/median WTA[10] of €517.47 (standard error 44.63) among these potentially interested PED suppliers. A simple linear extrapolation of the figures displayed in Figure 4 suggests that it would take an annual offer of some €2600 to get 100% of the homeowners with PVs or wind turbines to participate in a PED as suppliers. The probit regression in column (2) of Table A3.6 shows that only one variable is associated with the willingness to accept for participation, namely the length of time the respondents have lived in their homes. The longer such time, the less likely is participation at any given offer amount.

[9] In this case, the WTP is already elicited as per-year value. Hence it would amount to €198.86/148= €1.35 per m^2/year.
[10] Also in this case, the WTA is already elicited as per-year value. Hence it would amount to €517.57/148= €3.5 per m^2/year.

5. Conclusions

This report summarizes the results of Cultural-E Work Package 5, Task 5.2: "Estimation of co-benefits associated with Plus Energy Buildings (PEBs) at household level', and Task 5.3: "Estimation of co-benefits associated with PEBs at community level", related to project Deliverable 5.2 setting: "guidelines to assess co-benefits for the building occupants and used as input for marketing strategies for the developed technologies (T3.9), business models (T4.8) and the cost assessment of demo cases (T6.3)".

The co-benefits potentially originated by PEBs can be usually attributed to a "use". Accordingly, they can be evaluated by quantifying a "use value". This however can encompass both material and immaterial aspects where observable market transactions and official "prices" that can provide a support to the evaluation are not always evident. Accounting for these complexities, the present study proposes two different assessment methods: a direct costing approach and a discrete choice experiment approach.

A stepwise procedure involving a review of up-to-date literature employing a "direct costing" approach to value co-benefits of energy efficiency measures and verifying a preliminary data availability within the Cultural-E project, has been followed. The co-benefits eventually selected for the direct costing evaluation are at the household level: reduction of construction material and demolition waste and lower operational and maintenance costs; at the community level: mitigation of climate change, employment creation, improvement in social welfare (reduction in energy poverty), reduction in air pollution (reduction in emissions of particulate matter), reduced ozone depletion and tropospheric ozone photochemical oxidants, reduction in acidification potential, reduction in eutrophication potential, reduction in abiotic depletion potential for fossil and non-fossil resources and reduced water use.

It is emphasized that to evaluate co-benefits it is crucial to be able to compare the external costs attributable to a PEB with those of a nZEB. It is also important to note that in doing so, avoided pollutants and/or environmental impacts (that can originate co-benefits) will be assessed in relative terms compared to the reference nZEB. Furthermore, it should be emphasized that the embodied environmental impacts associated with advanced technologies employed in PEB's could result in a *higher* environmental impact, whereas during the operational phases, these technologies will lead to increased energy and operational efficiency, resulting in environmental gains.

The direct costing assessment clearly demonstrates that, in terms of co-benefits, there is not a clear prevalence of PEBs over the reference nZEB. PEBs and nZEBs outperform each other in some indicators (never in all) and these also differ across the cases study. This on the one hand witness quite some differences in the building techniques across countries (or firms), on the other hand suggests that our results are robust notwithstanding these differences. This, however, is hardly surprising as the nZEB already represents a benchmark with high “resource” and material efficiency standards which are difficult to be further improved upon. The main conclusion is that the major advantage (and source of benefits) of PEBs over nZEB is their energy generation potential. This is, however, their primary benefit and cannot be accounted for as a co-benefit.

More in detail, in the Italian case PEB A originates a co-benefit between 3.40-5.37 €/m^2*y, but PEB B originates a co-benefit loss of 1.81-1.97 €/m^2*y compared with the reference nZEB. In the German case the better performance of the PEB over the reference nZEB (that however is not dominated in all indicators) is more evident. It can be quantified in 97.2 - 99.9 €/m2*y. In the French case PEB and nZEB are almost identical with a dominance however of the nZEB.

The co-benefits, in this case more correctly “attributes”, finally selected for the stated preferences evaluation are the following: Energy Balance, that covers the energy features of the building, with a particular focus on energy security, Indoor Environmental Quality that covers the (highly subjective) perception of thermal comfort, visual comfort, and acoustic comfort, Adaptability that encompasses the ability of the building to adapt to user needs. The Price attribute, previously selected in the earlier phases of this study had to be replaced, for methodological reasons by the direct valuation by the respondents of the rental price of their dwelling in presence of alternative configurations of the other attributes.

For the stated preference assessment of co-benefits, we have conducted a survey of German and French homeowners living in the regions near the border between the two countries to obtain information about their preferences of a restricted selection of co-benefits, with a special focus on those related to (residential) energy security, which we have cast in terms of connection to a local network fed by renewables that provides electricity in the event of disruptions to the main grid and devices and software that optimize the energy consumption of appliances and heating/cooling.

We have chosen to use a different approach in eliciting the value of such energy security improvements and of the other co-benefits: instead of asking people whether they would connect to a PED or acquire such devices and software at a specified cost, which may or may not be a good predictor of actual behaviour should such opportunity arise, we have asked homeowners to first provide an estimate of the rental value of their homes, and then to tell us by how much the rental value would change in the presence of various combinations of such connections and devices. Our valuation scenarios also covered Indoor Environmental Quality, in terms of the presence or absence of a centralized air filtration system and the presence or absence of a centralized ventilation system, which of course contribute to the comfort and health of the residents. Moreover, it covered and Adaptability, in terms of the presence or absence of apps and sensor systems able to control and adjust appliance use and thermal conditions.

Our respondents were willing and able to estimate the rental value of their homes, and their guestimates depend systematically on the type of dwelling, the real estate market in the neighbourhood and characteristics of the area. Prior or current experience as a landlord, and the time a respondent has lived in their home, affect the reported rental values.

About 65% of the changes in rental value announced by the respondents under the hypothetical scenarios are zero, and many of these zeros are from respondents who said there would no change of value at *all* under all seven hypothetical scenarios they were asked to consider. We believe these “always zero” respondents are people who are unwilling or unable to engage in the hypothetical rental value exercises: They are to be found disproportionately among those who have lived in their home for a very long time (suggesting lack of familiarity with the current rental market) and among those who don’t have any prior or current landlord experience (likewise).

We eliminate for good measure the “always zero” subjects from the sample we use to relate the announced rental values under the hypothetical scenarios. Although this “clean” sample still contains many “no change” responses (over 50%), regression results indicate that the change in rental values do depend on the presence or absence of the energy security measures and the comfort/health systems in the hypothetical scenarios. Respondents who do not currently participate in a PED believe that such a connection is worth some €39/month; air filtration and mechanical ventilation systems are each valued €41/month, and systems of sensors and software that optimize appliance use or heating/cooling to save energy while maintaining comfort are worth €51/month and €39/month, respectively.

For PED participation, we collected additional information from the respondents, asking those who do not own microgeneration devices whether they would consider participating in a PED. We further queried them about paying €B, where €B is assigned at random to the respondents out of a preselected array. The responses to these simple binary questions allow us to trace out a PED participation curve as a function of €B and to estimate the mean/median WTP, which is some €441/year. This figure broadly agrees with that elicited through the hypothetical rent questions. Since more than half of the respondents without own PVs or wind turbine did not wish to subscribe to a PED, the sample-wide mean WTP is about €198/year. We also asked respondents whose home is equipped with PVs or a wind turbine whether they would be willing to participate in a PED as an electricity supplier and estimate their annual WTA to be some €517. Somewhat surprisingly, although we explained respondents in the questionnaire that a major benefit of PED network is that they maintain electricity service even when the national grid experiences disruptions, neither the WTP nor the WTA for PED participation depends on the number of outages experienced by the respondent.

We conclude based on this preliminary evidence that the possible appreciation of rental values (and presumably property values, which should be equal to the discounted flow of rental services) makes certain energy security and other health-related home improvements attractive to homeowners, and that such appreciation may be greater than the homeowners' WTP to obtain these improvements for themselves.

In future refinements, we will compare our survey respondents and their homes with the general population of the study area. We will also explore how the respondents' own satisfaction or dissatisfaction with air quality and the thermal comfort in the home, and their costs, affect the value they place on the improvements described in the hypothetical valuation scenarios. Finally, we will explore the role of hypothetical and actual outages and seek to compute a key metric in energy security and reliability assessments, namely the Value of Lost Load (VOLL).

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Appendix 1:

A worked example: Mediterranean low-rise solution set 1.

Here we provide a very practical example **of direct costing assessment** of the Global Warming Potential (GWP) embedded in the warming/cooling/insulating technologies applicable to a PEB.

The current assessment is applied to a Mediterranean “low rise” building, with a NFA of 700 m2. The service life is 20 years. Source data are made available by the LCA developed in Cultural-E.

The technology consists in a mix of: active window system (AWS Eurofinestra), a 200 m2 photovoltaics system for energy generation, an 80 Kg stainless steel storage system, a 600 m2 heating floor panel distribution system, a 1Kg-7Kw heat pump Air-Water heating system, a 5000 m²/h mechanic ventilation system.

LC - Embodied		62524.8487
Production		4.70976714
Waste		0.46741776
Recycling		-0.7111243
LC - Embodied	**/NFA*y**	**4.47**

According to the LCA, the technologies combined have a GWP of 62524.8 kg of CO2 equivalent embodied in their different production, waste and recycling phases. This enables **an estimate of the external costs associated with these technologies** that are used in the PEB, (**not for the whole building** though) that can be translated in economic terms using the social cost of carbon (SSC). The social cost of carbon has various values, depending on the assumptions and discount rate employed. This assessment uses “conservative ranges” ranging from a minimum of $5 to a maximum of $75 per ton of carbon in correspondence of a 7% to a 2.5% discount rate respectively (Rennert & Kingdon 2019).

The last row of Box Table 1 gives the social cost of carbon emissions or the GWP of the examined technologies applied to the examined PEB.

BOX table 1: economic assessment of the GWP of the technologies applied in the PEB under examination.

discount rate %	7	5	3	2.5
SCC (dollar per tonne)	5	14	50	75
SCC (dollar per kg)	0.005	0.014	0.05	0.075
LRSS1 med price carbon emissions	$312.62	$875.35	$3,126.24	$4,689.36

The direct costing method attaches to the technological mix an external cost due to its global warming potential, or said differently, to its originated climate change impact, of $312 to $4689.

Note that this is not yet a co-benefit measure. To translate the costs of carbon emissions into co-benefits it is necessary **to compare this value with what a nZEB** can originate.

Appendix 2: Stated Preferences Questionnaires

A. Detailed Questionnaire development

In what follows we describe the development of the questionnaire for assessing the value of EnergyPlus buildings co-benefits using a stated preferences approach along the border between France and Germany. We also provide insights on material which does not belongs to the questionnaire itself, but it is instrumental to determining its final design. This is because questionnaire design is not a linear process, but includes iterative steps, as illustrated in Figure A2. 1.

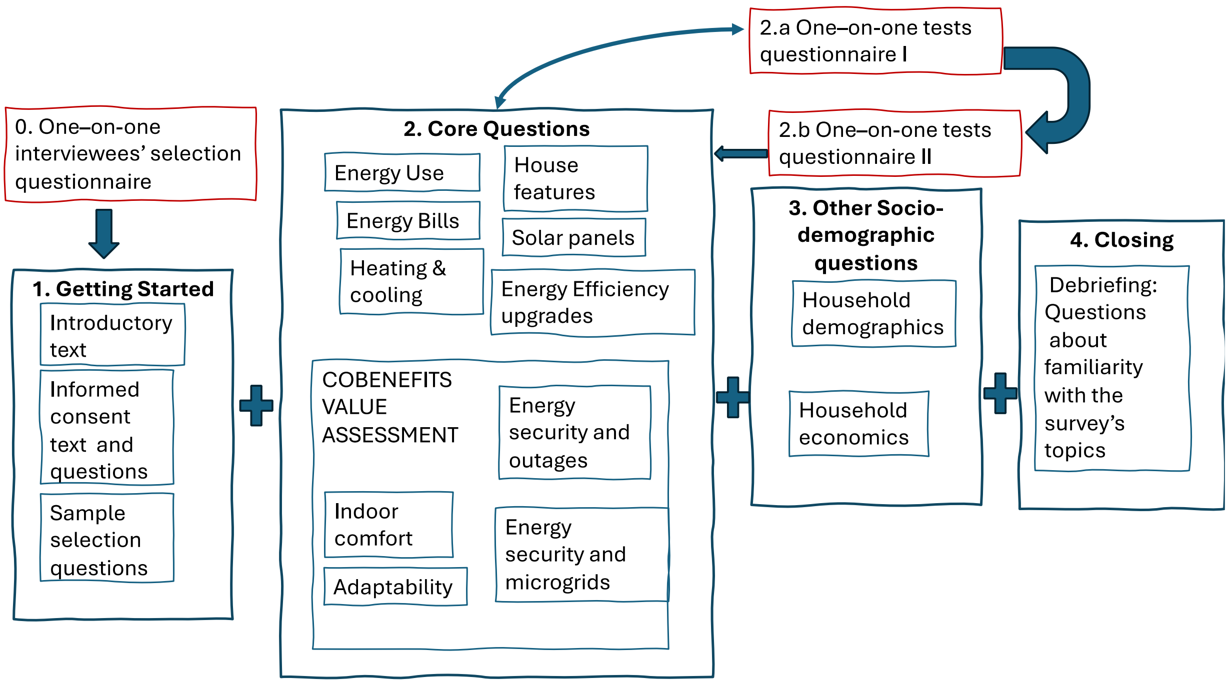

Figure A2. 1. Questionnaire development process

After the preliminary research phase and the drafting of the first, untested version of the questionnaire was concluded, we needed to test the questionnaire in order to make sure that the topics covered and the questions we pose are likely to be well understood by our sample. We thus recruited 16 test subjects among homeowners who are resident in the French Regions and German Länder covered by our study (those close to the France-Germany border). These people have been selected from the survey company's consumer panels, which counts millions of participants across Europe, by means of their usual channel, i.e. a small questionnaire launched on their survey platforms among their panellists living in France and In Germany. We relied upon the survey company to provide their names and contact details, and to compensate them for their time and feedback through the compensation scheme usually applied within their consumers' panel(s).

In order to fine-tune our questionnaire, we conducted 16 one-on-one tests, (eight for each country) in two stages. The first round helped us assessing the relevance of the specific co-benefits to be tested among those pre-selected by that research team, and/or adjust their characterisation in order to make them understandable for the respondents. The second round allowed us to check that we translated that information correctly into our questionnaire, and to test our value elicitation mechanism.

The **participant selection questionnaire** has some notable features which are replicated in the final questionnaire. The questionnaire begins by explaining the object of the interview and contains questions to check that the persons are not underage, that live in the regions of interest for our analysis that they own the place where they live, and that they are able to make decisions about energy use in their home. It also asks broad sociodemographic questions to get some background about the interviewees. Part B of this Appendix shows the pre-selection questionnaire and the interview outline for the one-on-one tests.

Once selected, the one-on-one test subjects were interviewed about topics likely to inform the content of the main questionnaire, by two members of the research team who are native speakers in German and French respectively. The interviews were carried out in two rounds, between February and May 2024. They lasted approximately between 30 minutes and one hour, were conducted online using the Zoom platform, and recorded to be analysed afterwards. The interviewers were trained by the research team about the way interviews were to be conducted, and debriefing sessions with the interviewers ensured that all the nuances of the information thus gathered were properly understood. We used a semi-structured approach: the interviewers had actual conversations with the one-on-one interviewees, encouraging them to talk extensively about their opinions.

Thus, the **questionnaire for the one-on-ones** looks more like a series of open questions to guide the conversation rather than a series of closed answer questions.

As it needs to be semi-structured to encourage the participant to disclose their actual views on the topics under scrutiny, it encompasses a series of open-ended questions, covering the various themes of the main questionnaire, thus, a) the main features of the dwelling, b) its energy-related characteristics, c) the level of indoor comfort perception as experienced in the dwelling d) the way energy consumption is billed and measured (with particular reference to smart meters); e) the experience with energy outages, f) the interest of the respondents about taking part in mini- or micro-grids and, in the second round, g) the value elicitation mechanism. Thus:

- under a) we ask questions like: what type of home do you live in, for how long have you live there? Do you plan to move?
- under b) we ask questions about the kind of heating system installed, the presence of air-conditioning, of solar panels, energy storage, smart meters (for electricity and for gas) the participation into net metering, and about any energy efficiency upgrades recently undertaken.
- under c) we ask about the presence of an air filtration system and to rate the various dimensions of indoor comfort as currently experienced by the interviewees in their dwelling.
- under d) we ask about of the billing frequency, the way smart meters are used (for instance if supplementary readings of the meters are required), and if they have noticed any increase in these bills.
- Under e) we ask about the experience with outages, in terms of their duration, frequency and period of occurrence.
- Under f) we inquire about the interviewees' interest in joining a mini-grid conditional to the ownership of PV panels, and their willingness to do so supposing that such choice would reduce the risk of outages.
- Under g) in the second round of interviews, we also tested our non-standard value elicitation mechanism through stated variations in the hypothetical rental price of the dwelling.

People interviewed have shown a good degree of familiarity with the main topics covered by the survey, also because a good share of them have invested in energy efficiency upgrades or in solar panels. The issue of outages is not regarded as a major threat, except when a major outage was experienced in the past; however, most people declared their interest in joining a mini-grid or a positive energy district. In a couple of cases, a limited budget was indicated as the main constraint for considering renovations or moving to a more energy efficient home. In the second round of interviews, all participants proved able to perform the value assessment exercise we designed, by providing their estimation of the rental price of their home, as well as the variation in this price (if any), as consequence of hypothetical changes in the co-benefits. This encouraged us to resort to such elicitation mechanism in the main questionnaire.

The main questionnaire

The final version of the questionnaire is shown in Part C of this Appendix. Since the latest version of this deliverable was submitted, several substantial changes to the questionnaire have proven necessary in order to maximise the chances of feasibility of our empirical analysis of co-benefits.

All sections of the questionnaire have been revised and refined. With such revisions we seized several opportunities to make our questions more poignant and consistent with our ultimate research goal, i.e. understanding the role and the value of PEBs' co-benefits. In many cases we drew on the lessons learnt from the one-on-one tests, and from the feedback of our native speaker colleagues, to make the wording of our questions more understandable and consistent with the French and German ways of living. The Reader is referred back to Section 4 in the main text for a concise description of the main questionnaire.

B. Pre-selection questionnaire and outlines for one-on-one tests

Questionnaire for one-on-one participants' selection.

Q.1 What is your gender?

1. male

2. female

3. non-binary

4. prefer not to say

Q.2 How old are you?

I_I_I **[range 1-99, EXCLUDE if <18]**

Q.3 In which region do you live?

	For France, show:	For Germany, show:
1)	Île-de-France	Bremen
2)	**Bourgogne-Franche-Comté**	Hamburg
3)	**Grand Est**	**Niedersachsen**
4)	Hauts-de-France	Schleswig-Holstein
5)	Bretagne	Nordrhein-Westfalen
6)	Centre-Val de Loire	Hessen
7)	Normandie	**Rheinland-Pfalz**
8)	Pays de la Loire	**Saarland**
9)	Nouvelle-Aquitaine	**Baden-Württemberg**
10)	Auvergne-Rhône-Alpes	Bayern
11)	Corse	Berlin
12)	Occitanie	Brandenburg
13)	Provence-Alpes-Côte d'Azur	Mecklenburg-Vorpommern
14)		Sachsen-Anhalt
15)		Sachsen
16)		Thüringen

For Germany screenout if not Q3=5,7,8,9

For France screenout if not Q3=2,3

Q.3A Please enter the enter the name of the municipality where you live:

_______________[type municipality]

Q4. Which of the following categories best describes your education level – that is, which is the highest education cycle you completed?

[omitted, see question Q28 in Appendix 3 - final questionnaire]

Q5. Do you own or rent your home?

[1] I own it

[2] I rent it **[SCREENOUT IF THIS ITEM IS SELECTED]**

[3] I live in this home but do not pay rent (e.g., housing provided by my employer or a family member) **[SCREENOUT IF THIS ITEM IS SELECTED]**

[4] other living arrangement **[SCREENOUT IF THIS ITEM IS SELECTED]**

Q6. Is your home…?

[1] a detached home

[2] a semi-detached home

[3] a terraced house

[4] an apartment within a multi-family building

[99] other, please specify **[………..]**

Q7. May we ask who is responsible for each of the following decisions regarding electricity, natural gas, and other fuels in your household?

continue the interview only if codes _c4 and c_5 are not selected for all three items.

1.Paying the bills	**2. Choosing a new supplier**	**3. Making any decisions that may result in saving energy (for example, changing appliances or doing renovations in the home)**

[1] myself [2] my spouse [3] another family member [4] no one: we don't pay for energy [SCREENOUT IF THIS ITEM IS SELECTED] [99] other, please explain:...[SCREENOUT IF THIS ITEM IS SELECTED]]	[1] myself [2] my spouse [3] another family member [4] no one: we don't pay for energy [SCREENOUT IF THIS ITEM IS SELECTED]] [99] other, please explain: .... [SCREENOUT IF THIS ITEM IS SELECTED]	[1] myself [2] my spouse [3] another family member [4] no one: we don't pay for energy [SCREENOUT IF THIS ITEM IS SELECTED] [99] other, please explain: .... [SCREENOUT IF THIS ITEM IS SELECTED]

Q8. Does your household get billed individually and directly for the electricity, heating, natural gas, and other types of energy it uses?

[1] yes

[2] yes, for some of them; for others, we share the expenses with the other households living in this building **[SCREENOUT IF THIS ITEM IS SELECTED]**

[3] no, they are included in the condominium fees **[SCREENOUT IF THIS ITEM IS SELECTED]**

[99] other, please explain **OE ______[SCREENOUT IF THIS ITEM IS SELECTED]**

Purpose of this interview

YOU FIT THE PROFILE OF PEOPLE WE ARE LOOKING FOR TO PARTICIPATE IN THIS SURVEY WE ARE THEREFORE ASKING FOR YOUR AVAILABILITY FOR 60/90 MINUTES TO CONDUCT AN INTERVIEW VIA ZOOM/TEAMS. IF YOUR PROFILE WILL BE CHOSEN AND YOU WILL COMPLETE THE INTERVIEW, YOUR SUPPORT TO THIS RESEARCH WILL BE COMPENSATED WITH €75 EQUIVALENT OF PANEL POINTS WICH WILL BE PAID AFTER THREE TO FOUR WEEKS FROM THE CLOSING OF THE INTERVIEW.

This survey is part of a research project funded by the European Commission, *Cultural-E*.

This study is about housing solutions and the energy efficiency in buildings, we will need to interview members of the general public about the homes they live in. We need your help to formulate the questions in that survey in the clearest way possible. No special experience or knowledge is required.

Your interview will take place in March 2024, will last between one hour and one and half hour, and will consist in a conversation about energy efficiency and its co-benefits that will help the researchers to fine-tune the final questionnaire of the main survey.

Q9. ARE YOU AVAILABLE TO PARTICIPATE IN THIS STUDY IN THE MANNER DESCRIBED ABOVE?

Informed consent

By this informed consent **you confirm that**:

- you are 18 years or older and
- you are competent to provide this consent.
- you have read the information about the interview.
- you are voluntarily taking part in this interview.
- you agree that the interview will be recorded (audio and video).

1. **I would like to participate in the interview, and I give my consent**
2. **I prefer not to participate [SCREENOUT]**

Q10. Please provide your telephone number:

…………………

Q11. Please provide your email address:

…………………

Q12. Please enter the postal code of the municipality of the place of you live.

I_I_I_I_I [type postal code]

Please note that the interview will be organised and conducted directly by the research institution in charge of this research activity within the project, Euro-Mediterranean Center on Climate Change (CMCC). The interview will be recorded. The research institution is bound, by a contractual agreement with Dynata and by European and national laws, to the highest confidentiality about your personal data. In particular, your contact details and the interview itself will be used exclusively for the purpose of the project and will not be released to any other party beside Dynata and CMCC.

One-on-one interview outline – second round

1. What type of home do you live in? (SF home, etc.)
2. How long have you lived in this home?
3. Do you have any plans to move to a different home within the next three years?
4. What type of heating system(s) do you have at your home? What fuels do they use?
5. Do you have any heat pumps at your home, as primary or secondary heating or cooling devices? Do you plan to install any heat pumps in the future?
6. Do you have A/C at your home?
7. Do you have solar panels at your home? Which type (PV to generate electricity, solar panels for hot water)? Do you plan to install any solar panel in the future?
8. If you have PV at your home, do you participate in net metering? Do you have batteries for storage?
9. Have you done any work (outside of standard maintenance) to your home in the last 5 years? If so, which? Any work to upgrade the energy efficiency of your home or insulate it? Did you receive any financial assistance from the government for them?
10. Please rate the following features of your home on a scale from 1 to 5 (where 1=very poor and 5=excellent):
    a. Warm in the winter
    b. Cool in the summer
    c. Indoor air quality
    d. Noise
    e. Quality of the natural light
11. Do you have an air filtration system?
12. How often do you pay your electricity bills? Your natural gas bills? The bills for any other source of energy? How often do you receive meter readings?
13. Do you have a smart meter at your home to measure your electricity consumption? What about your gas consumption?
14. If you don't have a smart meter, does your electricity provider require you to periodically read your meter and report your readings to them? If so, how often? On the

top of your reported readings, does your electricity provider independently check your consumption? If so, how often?

15. If you don't have a smart meter, does your gas provider require you to periodically read your meter and report your readings to them? If so, how often? On the top of your reported readings, does your gas provider independently check your consumption? If so, how often?
16. Did you experience any interruptions in the electricity or natural gas service…
17. …during the pandemic (Mar 2020-Dec 2021):…………………………….
18. …since the war in Ukraine (Feb 2022-present):……………………………
19. Please describe your experience with these interruptions. For example, how many times? How long were these interruptions? What did you do?
20. Have your electricity bills increased since early 2022?
21. What have you done in response to these increases?
22. If you have PVs, would you consider participating in a mini-network, so that the excess electricity you produce would be used to serve the residents and businesses in your neighborhood on a regular basis or during emergencies? (the connection would be done digitally and requires no effort on your part.)
23. Suppose that you received a lump-sum compensation for making your equipment and generation available for and connected to the local distribution network. How much would you require per year for this?
24. If you don't have PVs, would you consider participating in a network with neighboring residents and businesses, whereby you receive some of the pollution-free electricity generated by someone else in your neighborhood using PVs or other renewable sources—on a regular basis or during service emergencies? The connection to this mini-network would be done digitally and would require no effort on your part.
25. Suppose you would have to contribute an annual lump-sum fee to this mini-network. How much per year would you be prepared to pay to participate in this mini-network?
26. Imagine that the electricity grid is expected to have 3 outages of the approximate duration of 30 minutes in the next 12 months? How much would you be willing to pay to participate in the mini-network if it reduces the number of outages from 3 to 1?

One-on-one interview outline – second round

1. What type of home do you live in? (SF home, etc.)
2. How long have you lived in this home?
3. Do you have any plans to move to a different home within the next three years?
4. How much do you think a home like yours would rent for in your city or town? Please tell us what you think the monthly rent would be for a home like yours, unfurnished and not inclusive of utilities. *(Note for the interviewer: In case respondent find it difficult to*

provide a price, provide brackets such as less than 1000 euro, between 1000 and 1500, between 1500 and 2000, etc….)

5. What type of heating system(s) do you have at your home? What fuels do they use?
6. Do you have any heat pumps at your home, as primary or secondary heating or cooling devices? Do you plan to install any heat pumps in the future?
7. Do you have A/C at your home?
8. Do you have solar panels at your home? Which type (PV to generate electricity, solar panels for hot water)? Do you plan to install any solar panel in the future?
9. Did you receive any financial assistance from the government to install solar panels?
10. what made you decide to install solar panels?
11. If you have PV at your home, do you participate in net metering? Do you have batteries for storage?
12. Have you done any work (outside of standard maintenance) to your home in the last 5 years? If so, which? Any work to upgrade the energy efficiency of your home or insulate it? Did you receive any financial assistance from the government for them?
13. Please rate the outdoor air quality at the location where you live on a scale from 1 to 5, where 1=very poor (unhealthy) and 5=very good (healthy).
14. Please rate the indoor air quality inside your home on a scale from 1 to 5, where 1=very poor (unhealthy) and 5=very good (healthy). When answering this question, please think about conditions such as pollen, mold, dust and pollutants coming in from the outside.
15. Do you have an air filtration system?
16. How do you rate (from 1 to 5, where 1 is very poor and 5 is excellent) the following indoor comfort features:
    a. Warm in winter
    b. Cool in summer
    c. Noise
    d. Quality of the natural light

17. Now think about the monthly rent a home like yours is worth, as you told us in question 4 above. How much would the price change if the following features changed? Please consider them separately and one at a time.

    - The winter thermal comfort improved. For example, if it went from a rating of 4 to a rating of 5.
    - The summer thermal comfort improved
    - Indoor air quality improved
    - An advanced smart home system was installed that optimizes the temperature, humidity, light and air quality inside your home with minimum or no intervention on your part

- Your home was connected to a mini-network, so that the excess electricity produced in the network would be used to serve the residents and businesses in your neighborhood on a regular basis or during emergencies. The connection would be done digitally and requires no effort on your part. Consider these alternative scenarios:
    - Joining the mini-network would reduce the number of outages lasting 2 hours or longer, from 5 per year to 2 per year
    - Joining the mini-network would reduce the number of outages lasting 2 hours or longer, from 3 per year to 1 per year
    - Joining the mini-network would reduce the number of outages lasting 2 hours or longer, from 2 per year to zero

18. How often do you pay your electricity bills? Your natural gas bills? The bills for any other source of energy? How often do you receive meter readings?
19. Do you have a smart meter installed to measure your electricity consumption? What about your gas consumption?
20. If you don't have a smart meter installed does your electricity provider require you to periodically read your meter and report your readings to them? If so, how often? On the top of your reported readings, does your electricity provider independently check your consumption? If so, how often?
21. If you don't have a smart meter installed, does your gas provider require you to periodically read your meter and report your readings to them? If so, how often? On the top of your reported readings, does your gas provider independently check your consumption? If so, how often?
22. Did you experience any interruptions in the electricity or natural gas service…
23. …during the pandemic (Mar 2020-Dec 2021):…………………………….
24. …since the war in Ukraine (Feb 2022-present):……………………………
25. Please describe your experience with these interruptions (how many times? Duration? What did you do?)
26. Have your electricity bills increased since early 2022?
27. What did you do in response to these increases?
28. If you have PVs, would you consider participating in a mini-network, so that the excess electricity you produce would be used to serve the residents and businesses in your neighborhood on a regular basis or during emergencies? (the connection would be done digitally and requires no effort on your part.)
29. Suppose that you received a lump-sum compensation for making your equipment and generation available for and connected to the local distribution network. How much would you require per year for this?
30. *(Note for the interviewer: Skip this question and the next if the person has PVs).* If you don't have PVs, would you consider participating in a network with neighboring residents and businesses, whereby you receive some of the pollution-free electricity generated by

someone else in your neighborhood using PVs or other renewable sources—on a regular basis or during service emergencies? The connection to this mini-network would be done digitally and would require no effort on your part.

31. Suppose you would have to contribute an annual lump-sum fee to this mini-network. How much per year would you be prepared to pay to participate in this mini-network?

C. Final questionnaire (English master version)

Welcome to this survey! This survey is about energy efficiency in European buildings.

This survey is being conducted in two European countries by a consortium led by EURAC research, Bolzano, Italy. This study is part of the project Cultural-E, which is funded by the European Commission.

Your participation and your opinions are very important to us. This survey is not a quiz. There are no right or wrong answers to our questions. We are simply interested in your honest opinions.

This form contains important information about the reasons for undertaking this study, what you will be asked to do if you decide to be in the study, and the way information about you will be used if you choose to participate.

Time Required: We estimate that it will take you approximately 25 minutes to answer the questions in this survey. If you do not complete the questionnaire within a week, it will be assumed that you have withdrawn your consent, and none of your responses will be retained.

By completing the questionnaire, you **agree** that anonymous data from the questionnaire may be provided to third parties for non-commercial research. Any change to the above conditions is possible only with your explicit approval.

This project has received funding from European Union's Horizon H2020 innovation action programme under grant agreement N. 870072.

Informed consent

By this informed consent **you confirm that**:

- you are 18 years or older and
- you are competent to provide this consent;
- you have read the information about the survey (click here to read the information sheet);

- you are voluntarily taking part in this survey.

1. I would like to participate in the survey and give my consent **[CONTINUE]**
2. I prefer not to participate **[SCREENOUT]**

INFORMATION ON THE SURVEY (INFORMATION SHEET)

About the project

This survey is being carried out by Dynata (you can find **here**) more information about Dynata's privacy policy) on behalf of EURAC, CA' FOSCARI UNIVERSITY in Venice and the Euro-Mediterranean Center on Climate Change (CMCC) as part of the project *"Cultural-E- - Climate and cultural based design and market valuable technology solutions for Plus Energy Houses", funded by the EU Commission within the Horizon 2020 Programme under grant agreement N. 870072.*

You can find more information about the Project and its Partners **here**.

Purpose of this survey

The *Cultural-E* project aims to define modular and replicable solutions for Plus Energy Buildings, accounting for climate and cultural differences. An important part of this is endeavour, is understanding how people value the co-benefits of Energy Plus buildings, that is, the additional advantages in terms of the quality of indoor environment, energy security, sustainability etc. of living in a building that produces more energy than it consumes. This survey assesses people's attitudes towards these co-benefits in order to better inform the project's research and the policymakers with whom the project's results will be shared.

Confidentiality and sharing of the results

The data that you will share will be handled as confidentially as possible adhering to all pertinent standards and legislation. To minimize the risks of breaching confidentiality, we will collect only data that we need for the purposes of the described research project.

This survey will not require the insertion of personal data or information that may identify the relevant users, which will remain anonymous also to the researchers involved in the Project. However, before the publication or presentation of the results of this study, we will make sure that any personal data and other personally identifiable information (if any) will not be used. Hence, we will make sure that no answers you give can be traced back to you. Nonetheless, all partner institutions involved in the project adhere to the provision set in the European Union's General Data Protection Regulation (GDPR).

All scientific reports or publications based on this survey will present summary statistical information, such as averages or ranges. No information will ever be disclosed that could be linked to a particular person.

Who is responsible for the data collected in this study?

The work in the survey is being led by Andrea Bigano, PhD on behalf of the Cultural-E Partners. If you have any questions about this survey, you may contact Dr. Bigano at andrea.bigano@cmcc.it.

What are the benefits of participating in this study?

Panelists will be compensated according to the usual point scheme of the Dynata program. The study itself can be used to help design policies that better address people's concerns about climate change.

What if I have any ethical concerns about this research?

This survey has been reviewed and approved by Cultural-E's coordination team. If you are concerned about how this research is being conducted, you can contact the leader of the research team.

For more information

If you have any further questions or concerns about this survey, please visit the Cultural-E webpage at https://www.cultural-e.eu/ or contact Andrea Bigano (andrea.bigano@cmcc.it)

Screening questions

Q1. Do you own or rent your home?

[ ] own

[ ] rent — TERMINATE

[ ] I live in this home but do not pay rent (e.g., housing provided by my employer or a family member) — TERMINATE

[ ] other living arrangement, please explain…… TERMINATE

Q1a.In which region do you live?

1)	Alsace	Rheinland-Pfalz
2	Lorraine	Saarland
3)	Bourgogne	Baden-Württemberg
4)	Champagne-Ardenne	
5)	Franche-Comté	
6	Other region SCREENOUT	Other region SCREENOUT

SC

Q1b.Where do you live?

SHOW THE MUNICIPALITIES YOU WILL FIND AT SHEET "Municipalities in Germany/France" inside excel file culturalE rents, population, proximity and list of municipalities .xlsx **ACCORDINGLY TO EACH REGION AND RECODE THE KREIS / DEPARTMENT (COLUMNS B) AND REGION (COLUMN C). WE ALSO WOULD NEED TO HOOK POPULATION VARIABLE OF THE KREIS/DEPARTMENTS YOU**

CAN FIND AT COLUMN "F" INSIDE SHEET "RENTAL PRICE IN FRANCE/GRMANY".

QUOTA CHECK:

Border Proximity:

1= 50% of the sample

2= 30% of the sample

3= 20% of the sample

4=0%

SC

Q.2 What is your gender?

1. male
2. female
3. non-binary
4. prefer not to say

QUOTA CHECK:

1. Male n=500
2. Female n=500

Q.3 What is your age? (QA, range 1-99, Screen out if <18)

I_I_I

Section A: Your city and your neighborhood

SC

Q5 Where do you live?

[1] in a densely populated urban area

[2] in the suburbs or in a small town

[3] In a rural area

[4] other, please describe…………..

Q6. Which of the following best describes the neighborhood where your home is? Please select all that apply.

[ ] city center

[ ] residential area of a city or town

[ ] mixed-use area

[ ] up-and-coming neighborhood

[ ] neighbourhood that has been losing residents

[ ] the neighborhood is getting more and more attractive to families (and/or businesses)

[ ] the neighborhood is becoming a posh/luxury area

[ ] the neighborhood is becoming more and more affordable

[ ] the neighborhood is becoming less and less affordable

[ ] the neighborhood is getting less and less attractive to families (and/or businesses)

[ ] other, please explain……………………OE

Section B. GENERAL QUESTIONS ABOUT THE DWELLING

Q7. Is your home…?

[ ] a detached home

[ ] a semi-detached home

[ ] a terraced house

[ ] an apartment within a multi-family building

[ ] other, please explain ………..

SC

Q8. When was your home built?

[ ] In or after 2020

[ ] 2010-2019

[ ] 2000-2009

[ ] 1990-1999

[ ] 1980-1989

[ ] 1970-1979

[ ] 1960-1969

[ ] 1950-1959

[ ] Before 1950

[ ] I don’t know

Q9. When did you move into this home?

Month

Year I

Q10. How large is your home (m²)? Include bathrooms, kitchen, laundry room and exclude balconies and the basement.

I_I_I_I_I square meters

Q11. How many rooms are there in your home? Include bathrooms, kitchen, laundry room and exclude balconies and the basement.

I_I_I

HOME ENERGY USE

SC

Q12a. When you bought or moved into your home, were you shown the home's energy label?

[ ] yes

[ ] no

[ ] I don't remember

Q12b. What was the energy label of your home at the time you bought it or moved in?

(Answer option for France)

[ ] A [ ] B [ ] C [ ] D [ ] E [ ] F [ ] G [ ] I don't know

(Answer option for Germany)

[ ] A+ [ ] A [ ] B [ ] C [ ] D [ ] E [ ] F [ ] G [ ] H [ ] I don't know

Q12c. What is the energy label of your home at this time?

(Answer option for France)

[ ] A [ ] B [ ] C [ ] D [ ] E [ ] F [ ] G [ ] I don't know

(Answer option for Germany)

[ ] A+ [ ] A [ ] B [ ] C [ ] D [ ] E [ ] F [ ] G [ ] H [ ] I don't know

If current energy label is A+ in Germany or A in France

Q12d Is your home also classified as…?

[ ] Near Zero Energy Building or Zero Energy Building: (almost) all energy consumed is compensated by the energy generated by the building

[ ] Positive Energy Building: it generates more energy than it consumes and feeds it into the grid

[ ] other, please explain ………..

Q13. Which of the following best describes the main heating system in your home?

[1] condensing gas boiler

[2] gas boiler

[3] gas stove

[4] (air-to-air) heat pump

[5] (air-to-water) heat pump

[6] geothermal heat pump

[7] electric furnace

[8] resistance heaters

[9] electric heat in the floors

[10] passive solar system

[11] wood or pellet stove

[12] district heating

[13] fuel oil boiler or furnace

[14] other, please explain…….

[15] my home has no heating system

Q14. What type of fuels do you use to heat your home? Please select all that apply.

[ ] piped natural gas

[ ] propane in bottles or tank

[ ] electricity

[ ] heating oil

[ ] wood or pellets

[ ] other, please explain…………

Q15. What type of fuels do you use to heat water at your home? Please select all that apply.

[ ] piped natural gas

[ ] propane in bottles or tank

[ ] electricity

[ ] heating oil

[ ] wood or pellets

[ ] other, please explain…………

Q16a. Approximately when was your heating system last installed or replaced?

[ ] in the last 1-2 years

[ ] in the last 3-4 years

Q16. Approximately when was your heating system last installed or replaced?

[ ] in the last 1-2 years

[ ] in the last 3-5 years

[ ] 5 to 10 years ago

[ ] more than 10 years ago

[ ] I don't know

Q17. Some people use programmable thermostats and other devices to automatically turn on or off the heat or regulate the temperature in different rooms of their homes. Do you have one or more of these devices in your home? Please select all that apply.

[ ] yes, one programmable thermostat for the entire home

[ ] yes, thermostats for selected rooms or parts of the home

[ ] yes, thermostats installed on individual radiators

[ ] no

[ ] I don’t know

Q18. How do you cool your home in the summer? Please select all that apply.

[ ] central a/c

[ ] window or wall a/c in certain rooms

[ ] portable cooling units

[ ] electric fans

[ ] ceiling fans

[ ] other, please explain

[ ] none of the above

Q19. Which of the following do you have at your home? Please select all that apply.

[1] solar panels to generate electricity (PV)

[2] solar panels to heat water

[3] small wind turbine or other electricity generation technology

[4] batteries to store the electricity I produce

[5] none of the above

Q19.b Do you participate in net metering (which means you sell to the electricity grid the electricity that you generated but do not need)?

[ ] yes

[ ] no

[ ] I don’t know

Q19.c Do you participate in a positive energy district (which means you feed the electricity that you generate but do not need into a small network that distributes it to a community, such as neighbors)?

[ ] yes

[ ] no

[ ] I don’t know

Q19.d. Did you receive any subsidies or rebates to help you defray the cost of installing solar panels or small wind turbines? Please select all that apply.

[ ] yes, from the government

[ ] yes, from the electric utility

[ ] no

[ ] I don’t know

Q20. Is your consumption of electricity or gas measured using a smart meter?

By smart meter we mean an electronic device that records information—such as consumption of electric energy and communicates the information to the energy utility and to the consumer.

Please select all that apply.

[ ] yes—for electricity

[ ] yes—for gas

[ ] no

[ ] I don’t know EXCLUSIVE

Q21. Which of the following renovations were done in your home? Please select all that apply.

	In the last 3 years	4-5 years ago	6-10 years ago	More than 10 years ago	Never done
Building envelope insulation	[ ]	[ ]	[ ]	[ ]	[ ]
Wall insulation	[ ]	[ ]	[ ]	[ ]	[ ]
Attic insulation	[ ]	[ ]	[ ]	[ ]	[ ]
New heating system	[ ]	[ ]	[ ]	[ ]	[ ]
Energy efficient windows	[ ]	[ ]	[ ]	[ ]	[ ]
Basement insulation	[ ]	[ ]	[ ]	[ ]	[ ]
Kitchen or bathroom renovations	[ ]	[ ]	[ ]	[ ]	[ ]
Addition of rooms or					

expansion of the home	[ ]	[ ]	[ ]	[ ]	[ ]
Structural renovations (e.g., roof, or for compliance with seismic codes)	[ ]	[ ]	[ ]	[ ]	[ ]

Section C. Satisfaction with your home

Q22.a. On a scale from 1 to 5, where 1=very dissatisfied and 5=very satisfied, how satisfied are you with your home's thermal comfort in the winter?

[ ] 1 very dissatisfied [ ] 2 [ ] 3 [ ] 4 [ ] 5 very satisfied [ ] 6 not applicable

Q22.b. On a scale from 1 to 5, where 1=very dissatisfied and 5=very satisfied, how satisfied are you with your home's thermal comfort in the summer?

[ ] 1 very dissatisfied [ ] 2 [ ] 3 [ ] 4 [ ] 5 very satisfied [ ] 6 not applicable

Q22.c. On a scale from 1 to 5, where 1=very poor and 5=excellent, how would you rate quality of the air <u>inside your home</u>? Please think about whether there is pollen, mold , dust or odors inside your home.

[ ] 1 very poor [ ] 2 [ ] 3 [ ] 4 [ ] 5 excellent [ ] 6 not applicable

Q22.d. On a scale from 1 to 5, where 1=very poor and 5=excellent, how would you rate the quality of the air <u>outside your home</u>? Please think about whether there is air pollution, smoke, dust or pollen outside in the area where your home is.

[ ] 1 very poor [ ] 2 [ ] 3 [ ] 4 [ ] 5 excellent [ ] 6 not applicable

Q22.e. On a scale from 1 to 5, where 1=not insulated at all and 5=very well insulated, how well insulated is your home from <u>outside noises</u>? Please think about how much of the noise made outside by road traffic, people, aircraft or boats, or machinery you can hear inside your home.

[ ] 1 not insulated [ ] 2 [ ] 3 [ ] 4 [ ] 5 very well insulated [ ] 6 not applicable

Q22.f. On a scale from 1 to 5, where 1=very poor and 5=excellent, how would you rate the quality of the natural light inside your home? Please think about whether it is possible for you to read, knit or sew, or do any other activity without turning on lights in the daytime.

[ ] 1 very poor [ ] 2 [ ] 3 [ ] 4 [ ] 5 excellent [ ] 6 not applicable

Q22.g. On a scale from 1 to 5, where 1=very dissatisfied and 5=very satisfied, how satisfied are you with your home's mechanical ventilation system?

[ ] 1 very dissatisfied [ ] 2 [ ] 3 [ ] 4 [ ] 5 very satisfied [ ] 6 n/a (no vent. sys.)

Q22.h. On a scale from 1 to 5, where 1=very dissatisfied and 5=very satisfied, how satisfied are you with your home's air filtration system?

[ ] 1 very dissatisfied [ ] 2 [ ] 3 [ ] 4 [ ] 5 very satisfied [ ] 6 n/a (no filtr. sys.)

Q22.i. On a scale from 1 to 5, where 1=very poor value (=expensive) for the level of thermal comfort you experience and 5=very good value (=inexpensive) for the level of thermal comfort you experience, how would you rate your heating bills?

[ ] 1 ~~very poor value~~ expensive [ ] 2 [ ] 3 [ ] 4 [ ] 5 inexpensive [ ] 6 not applicable

Q22.j. Which of the following best describes the number of electricity outages of at least 5 minutes that you experienced in the last 12 months at your home?

[ ] 0 [ ] 1-2 [ ] 3-5 [ ] 6-10 [ ] 11 or more [ ] 6 not applicable

Section D. Rental value and valuation questions

Q23.a How much do you think a home exactly like yours and at this location would rent for in today's home rental market in the city, town or village where you live? Please think of the rent for a home like yours, unfurnished and not inclusive of utilities.

€……../month

PN: if the value entered at Q23.a, multiplied by the mq added at Q10, differs from the value found in column E, at of the excel file saved in Questionnaire folder named: "culturalE rents, population, proximity and list of municipalities .xlsx" by less than 50% or more than 70% show below question Q23.1

Q23.1 You said that the rental value of your house is [VALUE ENTERED AT Q23a]. Would you like to confirm that this is the value that you have in mind?

1. Yes, I confirm

2. No, let me revise

IF Q23.1=2

Q23.bis Let us ask you one more time .

How much do you think a home exactly like yours and at this location would rent for in today's home rental market in the city, town or village where you live? Please think of the rent for a home like yours, unfurnished and not inclusive of utilities.

€……../month

INTRO Q 23.b. Now we would like to ask you how much the rental value of your home might change if certain features were present in your home.

We will consider…

- Participation in a so-called positive energy district. This means that your home would be connected to a local, mini-network capable of delivering electricity generated from renewable sources, ensuring a continuous supply of electricity when the electricity service from the grid is interrupted due to outages or periods of extremely high demand.
    - The connection to this mini-network would be done digitally and would require no effort on your part.

    - Recent forecasts indicate that because of extreme weather events (e.g., more frequent and intense heat waves) and the transition to renewables, it is possible and likely that electricity outages may occur more frequently in the future.

- Mechanical ventilation—to make sure that there is moisture buildup, and hence mold, in your home.
- Air filtration system—to remove pathogens, dust, pollen, and air pollution from the outside
- System of sensors and associated software that optimizes the setting of the fridge, lighting, etc. to ensure maximum comfort while saving on energy bills. This software would be accessible through a computer or phone-accessible app.
- System of sensors and associated software that optimizes heating and cooling to ensure maximum comfort while saving on energy bills. This software would be accessible through a computer or phone-accessible app.

INTRO Q23.b-Q23.h. How much do you think a home like yours would rent for at this location and in today's rental market, if…

Total 7 cards

The physical display of each card would be approximately like this:

Number of expected outages per year (of the expected duration of 2 hours each)	~~2~~ 0 OR 1-2 OR 3-5 OR 6-7
PED participation	Connected OR Not connected
Ventilation	Available OR not available
Filtration	Available OR not available
App1	Available OR not available
App2	Available OR not available

Q23c You told us that the current rental value of your home is €………..[pipe answer from Q23.a].

Would the rental value of your home change under these conditions?

[1] no change

[2] it would increase

[3] it would decrease

IF Q23c=2,3

Q23 d By how much it would [IF Q23c=2: increase] [IF Q23c=3: decrease]?

€………../month [

If Q19.1 or Q19.3 is selected, then Q24 and Q24.b and Q24.d; else go to Q25. If 19.c.1 is selected, Go to Q 26

SC

Q24. If you have PVs or a small wind turbine, would you consider participating in a mini-network, so that the excess electricity you produce would be used to serve the residents and businesses in your neighborhood on a regular basis or during emergencies?

The connection would be done digitally and would require no effort on your part.

[ ] yes

[ ] no

[ ] I don't know

Q24.b. Suppose that you received a fixed compensation for making the electricity your generate available for and connected to the local distribution network. Would you accept € [PN: random pipe: 50, 100, 250, 500, 1000] per year for this?

[ ] yes

[ ] no

[ ] I don't know

Q24d What is the minimum amount of money per year that you would require?

€............./year

Ask if Q19=2, 4 (if the unique code selected) or 5

Q25. If you don't have PVs or a small wind turbine, would you consider participating in a network with neighboring residents and businesses, whereby you receive some of the pollution-free electricity generated by someone else in your neighborhood using PVs or other renewable sources?

You would be able to receive and use electricity from this mini-network on a regular basis or during service emergencies.

The connection to this mini-network would be done digitally and would require no effort on your part.

[ ] yes

[ ] no

[ ] I don't know

Ask if Q25=1

Q25.b. Suppose you would have to contribute an annual fixed fee to participate in this mini-network.

Would you pay € [PN: random pipe: of 50, 100, 250, 500, 1000] per year for this?

[ ] yes

[ ] no

[ ] don't know

Ask if Q25=1

Q25.c. What is the most you would pay per year to participate in this mini-network?

€............./year

Section E. Socio-demographics

Q.26 How many people is your household comprised of?

[ ] 1 (just me)

[ ] 2

[ ] 3

[ ] 4

[ ] 5

[ ] More than 5

Q27A. How many children under the age of 18 live with you at your home?

[ ] None

[ ] 1

[ ] 2

[ ] 3

[ ] 4

[ ] 5

[ ] More than 5

[ ] I prefer not to answer

Q27B. How many people aged 65 and older live with you at your home (including yourself, if your aged 65 or older)?

[ ] None

[ ] 1

[ ] 2

[ ] 3

[ ] 4

[ ] 5

[ ] More than 5

[ ] I prefer not to answer

Q28. Which of the following categories best describes your education level – that is, which is the highest education cycle you completed?

[PN: IF dCountry=1 Germany show below item list]

	Level:
[1]	Grundschule beendet Weiterführende Schule beendet ohne Abschluss oder noch Schueler
[2]	Volks-/Hauptschulabschluss Mittlere Reife/Realschulabschluss, Fachoberschulreife oder Mittlerer Schulabschluss Abschlusszeugnis Berufsgrundbildungsjahr; Berufsfachschule (Berufliche Grundkenntnisse); medizinische Hilfsberufe (1-jährige Schulen des Gesundheitswesens)

[3]	Fachhochschulreife (Abschluss einer Fachoberschule etc.) Abitur, allgemeine oder fachgebundene Hochschulreife bzw. Erweiterte Oberschule der ehem. DDR mit Abschluss 12. Klasse (Hochschulreife) Abschlusszeugnis für medizinische Assistenten, Krankenschwestern/ -pfleger (2- bis 3-jährige Schulen des Gesundheitswesens) Laufbahnprüfung für den mittleren Dienst beruflich-betriebliche Anlernzeit mit Abschlusszeugnis, aber keine Lehre; Teilfacharbeiterabschluss Abschlusszeugnis nach 2- bis 3-jähriger Ausbildung an einer Schule des Gesundheitswesens (medizinische Assistenten, Krankenschwestern/-pfleger) Abgeschlossene gewerbliche Lehre/duale Ausbildung in Industrie, Handwerk oder Landwirtschaft (Facharbeiter- oder Gesellenbrief) (Kaufmannsgehilfenbrief, IHK-Prüfungszeugnis) Berufsqualifizierender Abschluss einer Berufsfachschule/eines Kollegs (schulische Berufsausbildung)
[4]	Fachhochschulreife (Abschluss einer Fachoberschule etc.): Abschlusszeugnis Berufsgrundbildungsjahr, Berufsfachschule (Berufliche Grundkenntnisse), medizinische Hilfsberufe (1-jährige Schulen des Gesundheitswesens); beruflich-betriebliche Anlernzeit mit Abschlusszeugnis, aber keine Lehre; Teilfacharbeiterabschluss; Abschlusszeugnis für medizinische Assistenten, Krankenschwestern/ -pfleger (2- bis 3-jährige Schulen des Gesundheitswesens); Laufbahnprüfung für den mittleren Dienst; abgeschlossene gewerbliche oder landwirtschaftliche Lehre, Abgeschlossene kaufmännische Lehre, berufsqualifizierender Abschluss einer Berufsfachschule/eines Kollegs, berufliche Zweitausbildung
[5]	Zwischenprüfung, Vordiplom Diplom einer Berufsakademie (BA) Abschluss einer Ausbildung zum Erzieher/zur Erzieherin Meister-/Techniker- oder gleichwertiger Fachschulabschluss (inkl. Fachschule der ehemaligen DDR); Abschluss einer Verwaltungs- und Wirtschaftsakademie (VWA) oder Fachakademie (Bayern)
[6]	Diplom einer Verwaltungs-/Fachhochschule (FH, auch frühere Ingenieurschule) Laufbahnprüfung für den gehobenen Dienst Bachelor einer Universität (auch Kunst-, Musik-, technische, theologische oder pädagogische Hochschule)
[7]	Master einer Fachhochschule Diplom, Magister Artium oder 1. Staatsexamen einer Universität (auch Kunst-, Musik-, technische, theologische oder pädagogische Hochschule)

[8]	Promotion; Habilitation

[PN: IF dCountry=2 France show below item list]

	Level:
[1]	Ecole primaire uniquement Certificat d'études primaires Scolarité suivie de la 6ème à la 3ème
[2]	Brevet élémentaire, Brevet d'étude du premier cycle, Brevet des collèges Scolarité suivie de la 2nde à la Terminale
[3]	CAP, BEP, examen de fin d'apprentissage artisanal Diplôme d'aide soignante, auxiliaire de puériculture, aide médico-pédagogique, aide à domicile Baccalauréat professionnel, Brevet de technicien Baccalauréat technologique, Baccalauréat de technicien, BEA, BEC, BEI, BES Baccalauréat général, Brevet supérieur
[4]	Diplôme de la capacité en droit, Diplôme d'accès aux études universitaires (DAEU) Diplôme de moniteur-éducateur, Educateur technique spécialisé, Brevet Professionel
[5]	Diplôme universitaire du premier cycle (DEUG), Classes préparatoires aux grandes écoles Diplôme universitaire de technologie (DUT), Brevet de technicien supérieur (BTS) Certificat d'aptitude pédagogique (instituteur), Diplôme d'éducateur spécialisé, Diplôme d'assistante sociale, Diplôme paramédical (laborantin, infirmier, etc...)
[6]	Licence professionelle Licence
[7]	Diplôme d'école d'ingénieur DESS, Master deuxième année professionel Maîtrise, CAPES, CRPE (professeur des écoles) DEA, DES, Master deuxième année recherche, Agrégation Diplômes professionnels supérieurs divers (notaire, architecte, vétérinaire, journaliste…) Diplôme des grandes écoles

[8]	Doctorat en médecine ou équivalents (Médecine, Dentaire, Pharmacie, Vétérinaire) Doctorat

Q29. What is your household's total net monthly income from all sources? Please think of your take-home income after tax. *Please include all sources of income such as child support and other state support, interest, and other revenues. If you don't know the exact figure, please give us an estimate.*

1]	Less than € 500
[2]	Between € 501 and € 750
[3]	Between € 751 and € 1000
[4]	Between € 1001 and € 1250
[5]	Between € 1251 and € 1500
[6]	Between € 1501 and € 2000
[7]	Between € 2001 and € 2500
[8]	Between € 2501 and € 3000
[9]	Between € 3001 and € 3500
[10]	Between € 3501 and € 4000
[11]	Between € 4001 and € 4500
[12]	Between € 4501 and € 5000
[13]	Between € 5001 and € 5500
[14]	Between € 5501 and € 6000
[15]	Between € 6001 and € 7500
[16]	Between € 7501 and 12500
[17]	Over € 12500

[88]	I don't know
[99]	I prefer not to answer

Q30. How would you describe your current employment status?

[1] Employed full-time.

[2] Employed part-time.

[3] Self-employed

[4] Student

[5] Homemaker

[6] Employed but currently on maternity/paternity or parental leave.

[7] Retired

[8] Unemployed, looking for work.

[9] Unable to work due to sickness or disability.

[10] Other, please specify: ....

[99] I prefer not to answer.

Q31. Do you current own homes that you rent out to others, or have you previously rented out a home to tenants? Please select all that apply.

[ ] currently renting one or more homes out to tenants

[ ] previously rented out one or more homes to tenants

[ ] no

Q32. Do you, or any member of your household living with you, work in one of the following sectors? Please select all that apply.

[ ] energy sector

[ ] building and construction

[ ] manufacturing, of electric appliances

[ ] manufacturing of home climatization systems

[ ] manufacturing of doors and windows

[ ] sale and maintenance of electric appliances

[ ] sale and maintenance of home climatization systems

[ ] sale and maintenance of doors and windows

[ ] Local and national public administration

[ ] Public environmental agencies and authorities

[ ] Real estate

[ ] none of the above

[99] I prefer not to answer

Appendix 3: Figures and Tables for the co-benefits stated preferences evaluation.

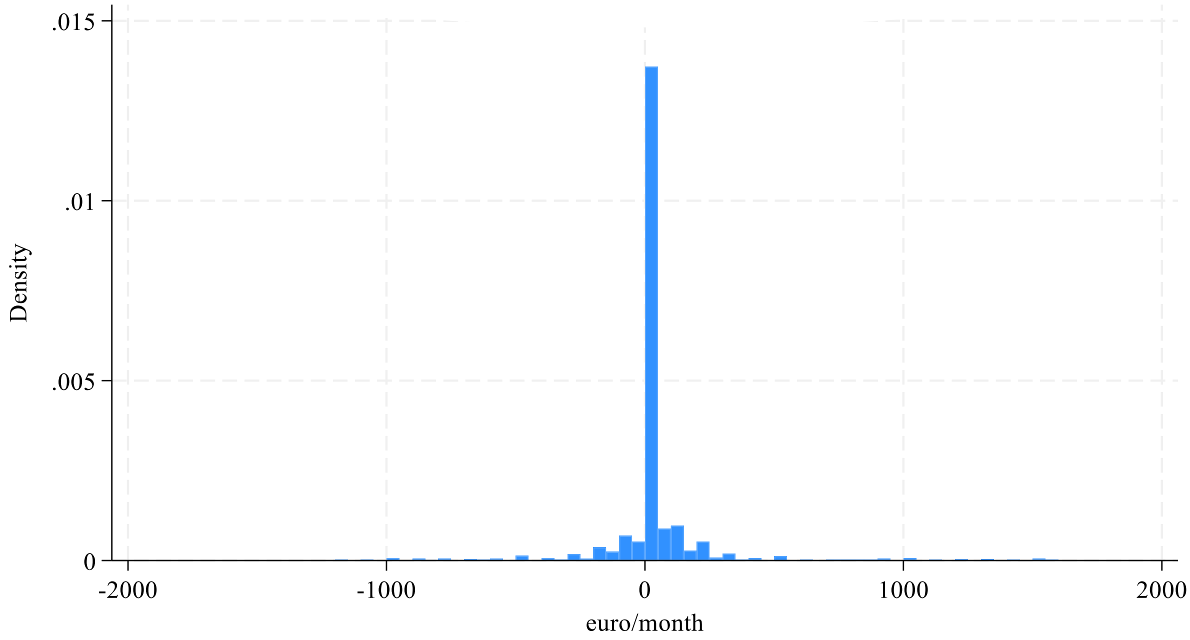

Figure A3.1 Change in rental value under hypothetical conditions

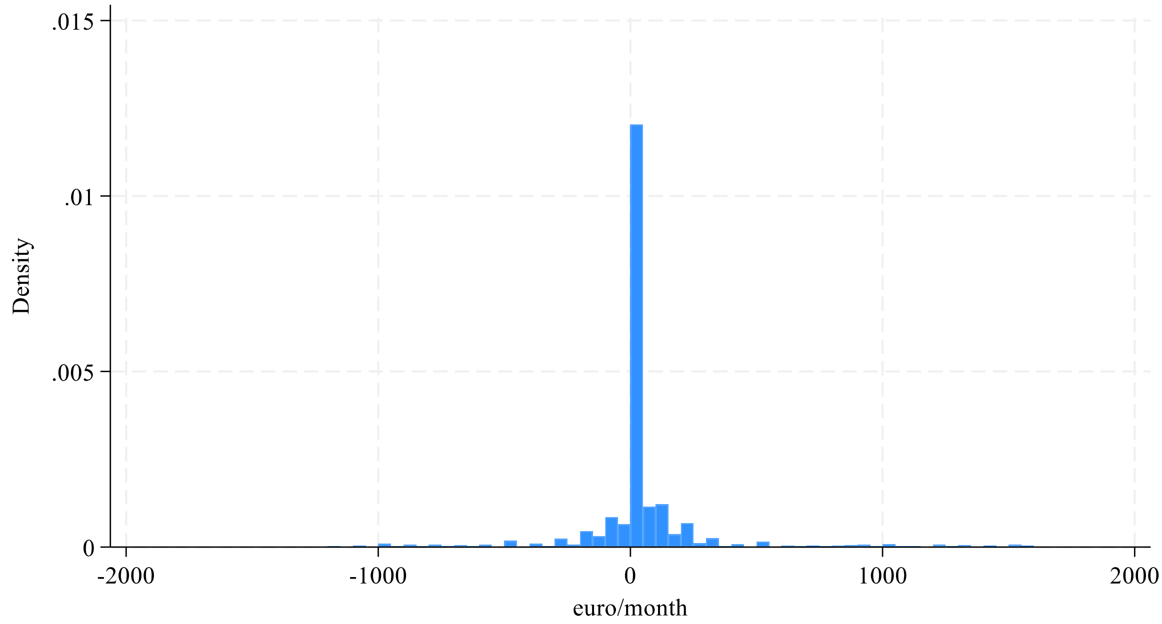

Figure A3.2: Change in rental value, excluding respondents who always report zero change.

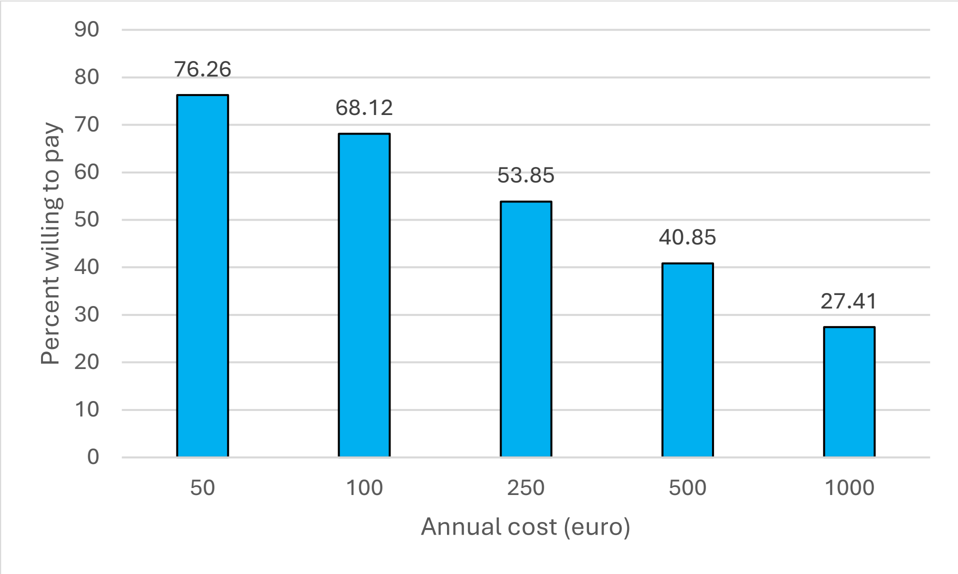

Figure A3.3: Willingness to Pay for PED participation. Percent of the 697 respondents willing to participate in a PED who are willing to pay the specified annual amount.

Figure A3.4: Willingness to Accept for PED participation. Percent of the 350 respondents equipped with PVs who are willing to participate in a PED as suppliers at the specified annual compensation amount.

	Rental value	
Zone 1	-96.358	*
	(42.178)	
Zone 2	28.505	
	(41.531)	
Zone 3	-6.856	
	(42.029)	
Germany	273.962	**
	(15.294)	
Urban	305.401	**
	(21.289)	
intermediate	274.245	**
	(17.549)	
City center	77.120	**
	(18.261)	
Residential area in a city	80.359	**
	(14.613)	
Mixed use area	131.867	**
	(19.156)	
Up-and-coming neighbourhood	153.474	**
	(17.995)	
Appreciating neighbourhood	-2.281	
	(20.669)	
Neighbourhood losing residents	87.490	**
	(32.119)	
More affordable neighbourhood	-23.319	
	(30.955)	
Detached house	335.770	**
	(94.757)	
Semi-detached house	219.718	*
	(96.215)	
Terraced house	153.575	
	(95.785)	
Multi-family building	102.390	
	(95.741)	
Square meters	2.279	**
	(0.073)	
Natural gas is main heating fuel	32.006	*
	(15.873)	
Electricity is main heating fuel	19.132	
	(15.432)	
Heating oil is main heating fuel	10.853	
	(19.767)	
Wood or pellet is main heating fuel	-1.747	
	(15.126)	
Has PV or wind turbine	134.796	**
	(14.098)	
Has experience as previous or current landlord	155.014	**
	(13.508)	
Months spent in this home	-0.321	**
	(0.034)	
Intercept	164.651	
	(104.740)	
Number of observations	13853	

** p<.01, * p<.05

Table A3.1. Rental value of the home under the current conditions. Linear Regression. Sample excludes top and bottom 1% of rental values, and observations with implausible number of square meters or rooms of the home

	(1)		(2)	
Building vintage category:				
2010-2019	-0.095		-0.093	
	(0.193)		(0.193)	
2000-2009	-0.367		-0.369	
	(0.192)		(0.192)	
1990-1999	-0.174		-0.175	
	(0.194)		(0.194)	
1980-1989	-0.219		-0.214	
	(0.195)		(0.195)	
1970-1979	-0.237		-0.234	
	(0.193)		(0.193)	
1960-1969	-0.398		-0.402	
	(0.210)		(0.210)	
1950-1959	-0.412		-0.417	
	(0.215)		(0.215)	
Before 1950	-0.275		-0.272	
	(0.194)		(0.193)	
Unknown	-0.248		-0.258	
	(0.239)		(0.239)	
Germany	-0.275	**	-0.271	**
	(0.088)		(0.088)	
Urban	-0.040		-0.077	
	(0.118)		(0.123)	
Intermediate	-0.151		-0.211	*
	(0.085)		(0.098)	
Detached house	0.418		0.420	
	(0.630)		(0.628)	
Semi-detached house	0.190		0.190	
	(0.637)		(0.635)	
Terraced house	0.362		0.363	
	(0.634)		(0.632)	
Multi-family building	0.350		0.355	
	(0.633)		(0.631)	
Square meters	-0.000		-0.000	
	(0.000)		(0.000)	
Natural gas is main heating fuel	0.073		0.074	
	(0.091)		(0.091)	
Electricity is main heating fuel	-0.230	*	-0.227	*
	(0.090)		(0.090)	
Heating oil is main heating fuel	-0.089		-0.090	
	(0.119)		(0.119)	
Wood or pellet is main heating fuel	-0.014		-0.012	
	(0.086)		(0.086)	
City center	-0.252	*	-0.252	*
	(0.108)		(0.108)	
Residential area in a city	-0.120		-0.120	
	(0.085)		(0.085)	
Mixed use area	-0.225	*	-0.226	*
	(0.114)		(0.114)	

Up-and-coming neighbourhood	-0.206		-0.211	*
	(0.106)		(0.107)	
Appreciating neighbourhood	0.002		0.006	
	(0.117)		(0.117)	
Neighbourhood losing residents	-0.244		-0.258	
	(0.185)		(0.185)	
More affordable neighbourhood	-0.228		-0.234	
	(0.180)		(0.180)	
Has PV or wind turbine	-0.083		-0.079	
	(0.082)		(0.082)	
Has experience as previous or current landlord	-0.266	**	-0.269	**
	(0.080)		(0.080)	
Months spent in this home	0.001	**	0.001	**
	(0.000)		(0.000)	
Zone 1			0.233	
			(0.236)	
Zone 2			0.147	
			(0.231)	
Zone 3			0.180	
			(0.234)	
Intercept	-0.418		-0.566	
	(0.656)		(0.689)	
Number of observations	2029		2029	

** p<.01, * p<.05

Table A3.2. Determinants of Always Zero Value Change: Probit Regressions

	(1)		(2)		(3)		(4)		(5)	
No PED in scenario offered to PED participant	32.528	*	35.066	*	38.074	*	36.398	*	38.325	*
	(14.035)		(14.544)		(16.167)		(15.981)		(15.970)	
Positive energy district in valuation scenario	37.899	**	38.512	**	38.850	**	38.468	**	38.819	**
	(5.722)		(5.787)		(5.853)		(5.806)		(5.811)	
Zero outages	-56.663	**	-150.760	**	-153.712	**	-139.795	**	-141.707	**
	(8.668)		(47.314)		(47.447)		(46.214)		(46.443)	
1-2 outages	-73.187	**	-167.174	**	-170.057	**	-155.837	**	-157.723	**
	(8.460)		(47.176)		(47.333)		(46.098)		(46.423)	
3-5 outages	-102.114	**	-197.548	**	-200.446	**	-186.294	**	-188.375	**
	(8.973)		(47.305)		(47.456)		(46.225)		(46.347)	
6-7 outages	-146.527	**	-241.718	**	-244.533	**	-230.709	**	-232.670	**
	(11.287)		(48.134)		(48.247)		(47.010)		(47.162)	
Ventilation system in valuation scenario	40.817	**	40.712	**	40.769	**	40.981	**	41.079	**
	(4.849)		(4.897)		(4.902)		(4.892)		(4.901)	
Filtration system in valuation scenario	40.384	**	41.437	**	41.493	**	41.676	**	41.960	**
	(4.909)		(4.880)		(4.884)		(4.871)		(4.869)	
Sensors & app for appliances	51.151	**	52.005	**	51.937	**	52.180	**	52.263	**
	(5.590)		(5.612)		(5.610)		(5.611)		(5.610)	
Sensors & app for heating/cooling	39.410	**	38.816	**	38.629	**	38.233	**	38.231	**
	(5.421)		(5.453)		(5.436)		(5.415)		(5.409)	
Detached house			110.991	*	108.045	*	103.214	*	106.795	*
			(45.745)		(45.946)		(44.105)		(42.843)	
Semi-detached house			113.898	*	111.739	*	108.684	*	107.064	*
			(46.610)		(46.676)		(44.850)		(43.555)	
Terraced house			131.791	**	129.381	**	124.895	**	124.775	**
			(46.237)		(46.312)		(44.456)		(43.269)	
Multi-family building			101.173	*	99.394	*	94.155	*	92.865	*
			(46.418)		(46.482)		(44.725)		(43.429)	
Square meters			-0.072		-0.069		-0.083		-0.107	*
			(0.049)		(0.050)		(0.052)		(0.052)	
Natural gas is main heating fuel			-4.387		-4.221		-7.278		-8.263	
			(8.659)		(8.673)		(8.518)		(8.568)	
Electricity is main heating fuel			-19.570	*	-18.251	*	-19.459	*	-19.820	*
			(9.100)		(9.147)		(9.196)		(9.186)	
Heating oil is main heating fuel			2.035		2.674		1.661		-8.808	
			(10.712)		(10.903)		(10.822)		(12.261)	
Wood or pellet is main heating fuel			-0.270		-0.111		-1.200		1.201	
			(9.079)		(9.100)		(8.945)		(9.052)	
Has PV or wind turbine					-2.794		-3.309		-8.588	
					(8.886)		(8.897)		(9.328)	
Has experience as previous or current landlord					-0.199		-2.084		-3.688	

			(8.726)	(8.935)		(8.915)	
Months spent in this home			0.023	0.028		0.027	
			(0.018)	(0.018)		(0.018)	
City center				-2.892		-1.453	
				(10.463)		(10.437)	
Residential area in a city				-13.006		-14.314	
				(7.769)		(7.778)	
Mixed use area				-5.765		-8.890	
				(9.621)		(9.743)	
Up-and-coming neighbourhood				6.784		5.277	
				(11.826)		(11.872)	
Appreciating neighbourhood				27.818		28.791	
				(15.555)		(15.457)	
Neighbourhood losing residents				-21.568		-21.712	*
				(11.183)		(11.023)	
More affordable neighbourhood				-32.715	*	-31.347	*
				(14.753)		(14.888)	
Germany						18.569	*
						(9.297)	
Urban						3.309	
						(12.599)	
Intermediate						-5.252	
						(8.746)	
Zone 1						1.677	
						(12.468)	
Zone 2						0.641	
						(11.192)	
Zone 3						-1.090	
						(11.935)	
Number of observations	10643	10516	10516	10516		10516	

** p<.01, * p<.05

Table A3.3. Rental value of the home under hypothetical conditions. Linear Regressions. Sample excludes top and bottom 1% of rental value change, observations with implausible number of square meters or rooms of the home, and respondents who always report zero rental value change.

	Germany		France	
PED in valuation scenario	45.987	**	29.079	**
	(9.321)		(6.567)	
No PED in scenario offered to PED participant	46.901	**	-2.230	
	(17.645)		(22.787)	
Zero outages	-69.299	**	-43.478	**
	(14.060)		(9.873)	
1-2 outages	-89.370	**	-55.577	**
	(13.834)		(9.556)	
3-5 outages	-125.284	**	-77.369	**
	(14.621)		(10.101)	
6-7 outages	-177.787	**	-113.736	**
	(18.852)		(11.891)	
Ventilation system in valuation scenario	54.556	**	26.527	**
	(7.946)		(5.344)	
Filtration system in valuation scenario	48.949	**	31.379	**
	(8.023)		(5.455)	
Sensors & app for appliances	65.804	**	35.406	**
	(9.194)		(6.019)	
Sensors & app for heating/cooling	43.916	**	34.746	**
	(8.862)		(5.973)	
Number of observations	5471		5172	
** p<.01, * p<.05				

Table A3.4. Rental value of the home under hypothetical conditions. Does it Depend on the Country? Linear Regressions. Sample excludes top and bottom 1% of rental value change and respondents who always report zero value change.

	(1)	(2)	(3)	(4)
Amount to participate in a PED as costumer	-0.001 **	-0.001 **	-0.001 **	-0.001 **
	(0.000)	(0.000)	(0.000)	(0.000)
Zero outages		-0.115		
		(0.124)		
1-2 outages		-0.213		
		(0.122)		
Detached house			-4.240	-4.190
			(166.966)	(147.559)
Semi-detached house			-4.212	-4.172
			(166.966)	(147.559)
Terraced House			-4.327	-4.319
			(166.966)	(147.559)
Multi-family building			-4.253	-4.281
			(166.966)	(147.559)
Detached house			0.001	0.001
			(0.001)	(0.001)
Natural gas is main heating fuel			-0.051	-0.044
			(0.149)	(0.153)
Electricity is main heating fuel			0.211	0.215
			(0.143)	(0.146)
Heating oil is main heating fuel			0.316	0.194
			(0.177)	(0.194)
Wood or pellet is main heating fuel			-0.057	-0.007
			(0.141)	(0.145)
Has PV or wind turbine			0.086	0.039
			(0.465)	(0.478)
Has experience as previous or current landlord			0.503 **	0.512 **
			(0.120)	(0.124)
Months spent in this home			0.000	0.000
			(0.000)	(0.000)
City center				0.126
				(0.169)
Residential area in a city				0.083
				(0.139)
Mixed use area				0.048
				(0.179)
Up-and-coming neighbourhood				0.288
				(0.166)
Appreciating neighbourhood				-0.209
				(0.191)
Neighbourhood losing residents				0.521
				(0.306)

More affordable neighbourhood							0.337	
							(0.291)	
Germany							0.276	*
							(0.137)	
Urban							0.034	
							(0.195)	
Intermediate							0.034	
							(0.158)	
Zone 1							0.388	
							(0.370)	
Zone 2							0.186	
							(0.362)	
Zone 3							0.223	
							(0.368)	
Intercept	0.572	**	0.685	**	4.442		3.884	
	(0.074)		(0.105)		(166.966)		(147.559)	
Number of observations	697		697		697		697	

** p<.01, * p<.05

Table A3.5. Participation in a PED. Probit models

	(1)		(2)	
Amount to participate in a PED as seller	0.001	**	0.001	**
	(0.000)		(0.000)	
Detached house			4.655	
			(143.841)	
Semi-detached house			4.758	
			(143.841)	
Terraced house			4.648	
			(143.841)	
Multi-family building			4.819	
			(143.842)	
Detached house			0.000	
			(0.001)	
Natural gas is main heating fuel			0.144	
			(0.202)	
Electricity is main heating fuel			-0.134	
			(0.190)	
Heating oil is main heating fuel			-0.064	
			(0.212)	
Wood or pellet is main heating fuel			-0.140	
			(0.180)	
Has experience as previous or current landlord			0.225	
			(0.159)	
Months spent in this home			-0.001	*
			(0.000)	
City center			0.143	
			(0.254)	
Residential area in a city			0.152	
			(0.186)	
Mixed use area			0.072	
			(0.227)	
Up-and-coming neighbourhood			0.214	
			(0.210)	
Appreciating neighbourhood			-0.137	
			(0.269)	
Neighbourhood losing residents			0.635	
			(0.560)	
More affordable neighbourhood			0.664	
			(0.568)	
Germany			-0.265	
			(0.196)	
Urban			0.521	
			(0.281)	
Intermediate			0.380	
			(0.263)	

Zone 1			-0.635
			(0.497)
Zone 2			-0.627
			(0.485)
Zone 3			-0.202
			(0.495)
Intercept	-0.317	**	-4.763
	(0.102)		(143.842)
Number of observations	350		347

** p<.01, * p<.05

Table A3.6. Participation in a PED as supplier. Probit models.