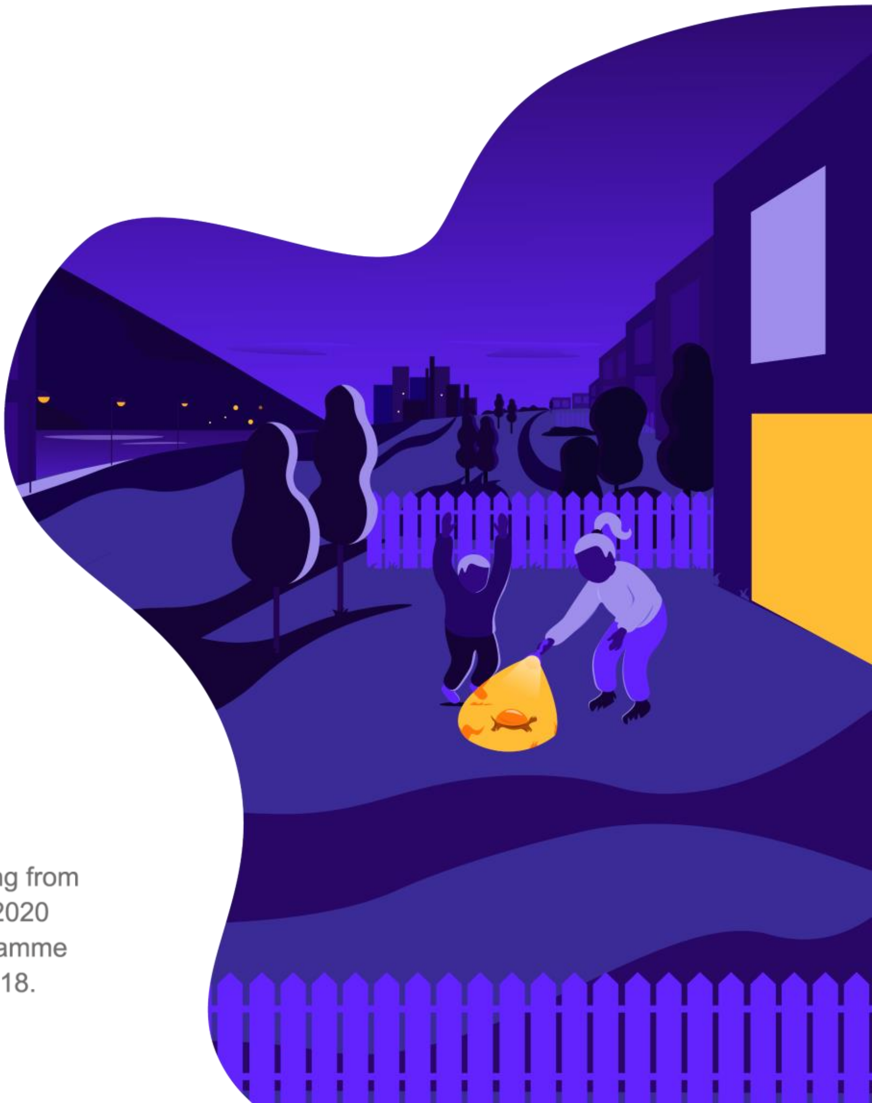
Sustainable
plus energy
neighbourhoods

A methodology report on the required calculations for the quantification and monetisation of multiple benefits

DELIVERABLE 5.4

Sheikh Zuhaib, Sriraj Gokarakonda, Victoria Taranu (BPIE)

M54



This project has received funding from
the European Union's Horizon 2020
Research and Innovation programme
under Grant Agreement N 869918.

Revision Log:

PROJECT ACRONYM syn.ikia

PROJECT NUMBER 869918

PROJECT TITLE Sustainable Plus Energy Neighbourhoods

WEBSITE www.synikia.eu

Technical References

Deliverable (number)	D5.4
Deliverable Name	A methodology report on the required calculations for the quantification and monetisation of multiple benefits
Work Package (number)	WP5
Task number and Title	T5.3
Dissemination Level	PU
Date of Delivery	30.06.2024
Lead Beneficiary	Buildings Performance Institute Europe
Contributors	Joana Ortiz, Jaume Salom – IREC, Ábel Magyari - ABUD, Hannes Harter- NTNU
Reviewers	Joana Ortiz (IREC)
Status	Final

Executive Summary

Sustainable plus energy neighbourhoods (SPENs) provide numerous social, economic, and environmental benefits, aligning with the three pillars of sustainability. These benefits extend beyond individual buildings to impact entire communities, including cost reductions through economies of scale, enhanced social cohesion,

improved public health and wellbeing, increased inclusion and accessibility, better community facilities, and safer public spaces. Some benefits are measurable, while others are not.

For policy-related decision-making, a benefit must have a direct link to its market valuation. Depending on the project's complexity, various calculation methods and models, such as Life-cycle Assessment, Multi-criteria Analysis, and Social Cost-Benefit Analysis (SCBA), may be used. SCBA is favoured for its simplicity and comprehensive coverage of impacts like health, energy, and income. The valuation of environmental quality changes includes use values (derived from the direct and indirect use of goods like agriculture and water purification) and non-use values (existence, altruist, and bequest values). Valuation methods mainly rely on willingness to pay (WTP) or willingness to accept (WTA), with WTP preferred for consistency. Techniques include market-based approaches, revealed and stated preference methods, subjective well-being assessments, and the benefit transfer method, which allows for applying valuation estimates across different contexts. These methods aim to capture and quantify the social value of environmental changes by reflecting people's preferences and welfare impacts.

MBx tool, developed within syn.ikia project, is a step forward in quantifying and monetising the social welfare, micro-economic and environmental benefits of projects, by considering the added values of the SPEN approach. This decision-making tool for policymakers and investors uses social cost-benefit analysis method to compare the benefit-cost ratio and return-on-investment of SPEN against that of BAU. For example, it can help investors identify ESG investment opportunities and future-proof real estate assets.

The MBx tool is explained in a series of three deliverables.

- A methodological framework for identifying the multiple benefits of SPENS was developed and presented in the deliverable *D5.3 Multiple benefits of sustainable plus energy neighbourhoods and their potential impact on policy and investment decisions*.
- **This research report, D5.4, provides a simplified methodological framework for quantifying and monetising multiple benefits with direct implications for SPENS**. Particular emphasis is placed on the development of an easy-to-use tool, ***MBx tool***, to enable the assessment of specific localised multiple benefits and social cost-benefit analysis. **Chapter 2 discusses different methods and frameworks for quantifying and monetising these benefits, Chapter 3 details how to assign monetary values to them, and Chapter 4 covers specific calculation approaches for each benefit listed in the MBx tool's impact database.**
- The MBx tool and its operation are explained in the deliverable *D5.5 A web-based calculation tool to support decision-making and investment*.

1. Table of contents

Acronyms

BAU	Business-As-Usual
BCR	Benefit-Cost Ratio
CBA	Cost Benefit Analysis
CGE	Computable General Equilibrium
CM	Choice Modelling
CO2	Carbon dioxide
COI	Cost of Illness
CVM	Contingent Valuation Method
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council)
DOE	Department of Energy
DSGE	Dynamic Stochastic General Equilibrium
EC	European Commission
EPC	Energy Performance Certificate
ERR	Economic rate of return
ESG	Environmental, Social, and Governance
EU	European Union
GHG	Greenhouse Gas
GP	General Practitioner
IAM	Integrated Assessment Modelling
IEQ	Indoor Environmental Quality
IRR	Internal Rate of Return
JRC	Joint Research Commission
LCA	Life Cycle Analysis
LCC	Life Cyle Costs
LCCA	Life-Cycle Cost Analysis
MAC	Marginal Abatement Cost
MACC	Marginal Abatement Cost Curves
MB	Multiple Benefits
MBA	Multiple Benefit Analysis
MCA	Multi Criteria Analysis
MFH	Multifamily Housing
MVHR	Mechanical Ventilation Heat Recovery
NO2	Nitrogen dioxide
NOX	Nitrogen oxides
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
PM10,	Particulate Matter 10
PM2	Particulate Matter 2
QALY	Quality-adjusted life year
RES	Renewable energy systems
ROI	Rate of Interest
SCBA	Social Cost Benefit Analysis

SFH	Single-family Homes
SLCA	Social Life Cycle Analysis
SPEN	Sustainable Positive Energy Neighbourhood
SWB	Subjective Well-Being
USEPA	United States Environmental Protection Agency
VOLY	Value Of a Life (Year)
VSL	Value Of a Statistical Life (Year)
WTA	Willingness-to-Accept
WTP	Willingness-to-Pay
WWHR	Wastewater Heat Recovery

1. Introduction

Sustainable plus-energy neighbourhood (SPEN) is an innovative concept of decarbonising the building stock which is being tested within the Horizon 2020 project syn.ikia. SPENs aim for high energy efficiency to reduce energy demand and achieve a positive energy balance at the neighbourhood scale. SPENs require additional investments compared to business-as-usual (BAU) projects, however, they also provide multiple added social, economic and environmental benefits. At a societal level, they contribute to lower GHG emissions, leading to lower mortality and morbidity rates. Improved accessibility to public and cycling infrastructure contributes to physical and mental health, as well as inclusion and affordability. At an individual level, improved Indoor Environmental Quality (IEQ) yields health and productivity benefits for the dwellers. Such projects rely heavily on public funding; to scale up SPEN to the private residential sector, therefore, there is an increased need to access private funding. The EU Taxonomy and ESG Finance encourage sustainable investments in real estate. Investors, asset managers and policymakers need evidence-based and commonly accepted methodologies to assess ESG aspects of projects. Studies in the building and construction sector have calculated multiple benefits using cost-benefit analysis. However, the multiple benefits of Sustainable Plus Energy Neighbourhoods (SPENs) have not been sufficiently explored and none of the existing frameworks or methodologies have been used for this purpose. The main challenge remains the lack of a methodological framework, data to quantify the impacts and a tool to do so.

MBx tool, developed within syn.ikia project, is a step forward in quantifying and monetising the social welfare, micro-economic and environmental benefits of projects, by considering the added values of the SPEN approach. This decision-making tool for policymakers and investors uses Social Cost-Benefit Analysis method to compare the benefit-cost ratio and return-on-investment of SPEN against that of BAU.

MBx tool can help investors identify ESG investment opportunities and future-proof real estate assets. The MBx tool is explained in a series of three deliverables. A methodological framework for identifying the multiple benefits of SPENS was developed and presented in the deliverable *D5.3 Multiple benefits of sustainable plus energy neighbourhoods and their potential impact on policy and investment decisions*. This research report, D5.4, provides a simplified methodological framework for quantifying and monetising multiple benefits with direct implications for SPENS. Particular emphasis is placed on the development of an easy-to-use tool, ***MBx tool***, to enable the assessment of specific localised multiple benefits and social cost-benefit analysis. The tool and its operation are explained in another deliverable *D5.5 A web-based calculation tool to support decision-making and investment*.

2. Methods and frameworks of quantification and monetisation of multiple benefits

The term '**multiple benefits**' usually refers to the many potential intended or unintended benefits to stakeholders of a policy or project that go beyond its primary objectives. In the context of energy efficiency investments, multiple benefits refer to benefits beyond those related to energy, such as savings in energy consumption and costs. These non-energy-related benefits include increased productivity, better health, improved educational outcomes, reduced need for new energy infrastructure, increased property values, employee satisfaction and retention, job creation and economic development. Research and several EU-funded projects [1],[2],[3] have identified, and in some cases quantified and valued (i.e. monetised), several sets of multiple benefits. These projects have consistently shown that the non-energy benefits outweigh the energy benefits.

For a benefit to be considered in policy-related decision-making, the outcome should have a direct link to its market valuation [4]. In other words, in most cases the impact on the end user, investor or other beneficiary should be monetised. For example, benefits related to employee productivity can be valued as financial gains and benefits related to health can be valued as healthcare costs. The scope and complexity of the policy objective or project will determine the most appropriate calculation methods, modelling approaches or other complex models that may be used for valuation purposes, i.e., monetisation. It is theoretically possible to estimate a monetary value for each benefit. This is achieved by first quantifying the impact of the measure in physical units (e.g. number of life years saved, number of full-time jobs created, tonnes of CO2 avoided etc.) before translating this into a monetary value. For non-market goods and services, the valuation is typically carried out by estimating the willingness to pay for benefits or the willingness to accept compensation for losses (e.g. avoided costs, replacement costs, contingent valuation, hedonic pricing etc.).

However, there have been certain concerns regarding the use of economic valuation methodologies and the commodification of ecosystems and social welfare, which have raised some ethical implications. Although numerous case studies and research projects have demonstrated the potential for monetising multiple benefits, the practical application of this approach remains a challenge for decision-makers, such as e.g. investors and policymakers. Previous studies and research were focused generally on economic and environmental impacts [5]. However recently, several studies have outlined and quantified social impacts, such as effects on living conditions [6]. In the COMBI project, several interactions were studied, and methods were proposed to operationalise multiple impacts into energy efficiency policy decision-making. It found that multiple impacts sum up to a size of 50% of energy cost savings and have substantial impacts on air pollution, energy poverty reduction and other macro-economic indicators [7]. In a larger study by Reuter et. al. [8], a set of 20 indicators were identified for the quantification of multiple benefits of energy efficiency, divided mainly under economic, environmental, and social categories. The findings form a part of the ODYSSEE-MURE database [9].

Numerous frameworks have been developed for the assessment of the multiple impacts to incorporate the multiple benefits into the decision-making process. One such framework is cost-benefit analysis (CBA) which is generally based on life-cycle cost analysis (LCCA) or net present value (NPV) and uses real-time inflation, discount factors and investments. Another framework, Multiple Benefit Analysis (MBA), sometimes known as Multiple Criteria Analysis (MCA), can be used to compare various scenarios in a single framework. Approaches based on MCA can indeed be used to consider impacts that cannot be monetised. For the results based on these frameworks to be legitimised by stakeholders, a consultation process is usually required. A more holistic approach is life-cycle assessment (LCA), which also considers the analysis of potential environmental loads and resources [10]. This approach has been used in the EERA data project, where they developed a tool to support policy decisions and renovation action to prioritise investments in energy efficiency [11]. Similar to CBA, economic rate of return (ERR) or internal rate of return (IRR) can also be used for such calculations if the multiple benefits are monetised and included in the calculation [12]. Some of the most used frameworks are described in the following subsections.

Social Cost Benefit Analysis (S-CBA)

S-CBA is an application of welfare economics principles to normative questions around investment choices [13]. It is based on the assessment of changes in welfare benefits and costs, expressing them all in the common currency of monetary values to calculate the net effect on the total economic wellbeing of society. Welfare effects are changes in health and well-being, which, measured in economic terms as producer surplus (increases in the profitability of production) and consumer surplus resulting from the expansion of people’s consumption possibilities [14]. This includes their access to services, publicly provided non-market goods and natural environment services, such as the air and water quality, access to nature and general amenity infrastructure.

‘The broad purpose of S-CBA is to help social decision-making and to increase the social value or, more technically, to improve allocative efficiency’ [15]. S-CBA is a social investment appraisal technique that considers the full effects of a project on the affected community, rather than focusing on the private perspective of the project's supporters. As a modified investment appraisal process, its endpoint is an estimation of an activity’s economic surpluses, net of costs and externalities, to the extent that they can be measured. Not all items included in an S-CBA can be quantified in monetary terms. However, techniques of non-market valuation have been developed to extend the monetised S-CBA beyond the scope of items traded in markets.

The valuation of a project in S-CBA is based on the preferences of the public, as expressed through the prices of market goods or inferred through other means for non-market effects. The value of improvements in wellbeing is commonly inferred from the maximum amount of affected individuals’ willingness to pay (WTP) for an improvement in wellbeing or the minimum amount of individuals’ willingness to accept (WTA) as compensation for a drop in wellbeing. The sum of these amounts across the community indicates the societal value of gaining the improvement or bearing the drop. Thus, social cost-benefit analysis is the preferred appraisal tool because it measures costs and benefits as variations in human well-being (i.e., in utility), thus estimating the net contribution of each of the defined project or policy options to the aggregated welfare of the society.

The term monetisation is often associated with commercialisation, but this is not the objective of monetisation in S-CBA. Instead, it aims to provide comparable values for all significant impacts of an investment, thereby avoiding the alternative of having some items implicitly treated as having zero value or weighed up outside of the monetary analysis, which may lead to inconsistent weightings across decisions.

Two fundamental principles underpin the conduct of a cost-benefit analysis (S-CBA), namely:

1. The demonstration of an investment as being both financially viable and offering a greater value for money proposition than its associated costs.
2. The comparison of the efficiency of the investment in question against that of other potential investments and the subsequent ranking of them according to their benefit-cost ratio (BCR)

$$BCR = \frac{PN(B)}{PV(I + C)}$$

where PV is the present value, B is benefits, I is a capital investment and C is all other costs.

The following steps should be taken when undertaking a social cost-benefit analysis (S-CBA):

1. Establish the purpose of S-CBA, which may include informing policy, investment in a project or other considerations
2. Specify the set of projects, scenarios or alternatives that will be evaluated
3. Decide whose benefits or costs will be included in the analysis, e.g., relevant stakeholders
4. Identify the impact categories and the metrics selected
5. Predict the impact over the life cycle of the project
6. Monetise all impacts, with euro values attached
7. Discount benefits and costs to obtain Present Values
8. Compute the Net Present Value (NPV) for each project, scenario or alternatives
9. Perform a sensitivity analysis
10. Make recommendations

Life-cycle assessment

Life Cycle Assessment (LCA) evaluates the environmental impact of a product throughout its life cycle. Several frameworks and methodologies have been developed to perform LCA, including ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework and ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and Guidelines. This framework typically involves [16]:

1. defining the objective and scope of the assessment,
2. analysing the life cycle inventory needed to perform the assessment,
3. assessing the impacts using the chosen methodology, and
4. interpreting the results of the assessment and revising the objectives and scope if necessary.

A building-specific LCA approach is commonly used to assess the sustainability of buildings or the built environment, for example in the DGNB green building rating system [17]. Building-specific LCA standards such as ASTM E2921-22 also facilitate this. In general, environmental LCA is conducted for indicators such as global warming potential, ozone depletion potential, and total primary energy demand. One of the limitations of LCA is that it is unable to perform social and economic analysis independently. Nevertheless, novel methodologies are emerging which utilise LCA for cost-benefit analysis. These combine LCA with Life Cycle Costing (LCC) and Social Life Cycle Analysis (SLCA) or CBA to calculate the impact of categories such as local employment, with indicators such as the number of jobs created [18], [19].

Multi-criteria Analysis

Multi-criteria analysis (MCA) is a family of algorithms used to select alternatives according to a set of different criteria and their relative ‘weights’. In contrast to S-CBA, which focuses on a unique criterion (the maximisation of social welfare), MCA is a tool for dealing with a set of different objectives that cannot be aggregated through shadow prices and welfare weights, as in standard S-CBA [20]. MCA is appropriate for development programmes, pursuing simultaneously different policy objectives (e.g. equity, environmental sustainability, improved quality of life, etc.), rather than for the appraisal of a single investment project.

There are many ways to design an MCA exercise. One possible approach is as follows:

- objectives should be expressed in measurable variables. They should not be redundant but could be alternative (the achievement of a bit more of one objective could partly preclude the achievement of the other);
- once the ‘objectives vector’ has been determined, a technique should be found to aggregate information and to make a choice; the objectives should have assigned weights reflecting the relative importance given to them by the policy-maker;
- definition of the appraisal criteria; these criteria could refer to the priorities pursued by the different parties involved or they could refer to particular evaluation aspects;
- impact analysis: this activity involves describing, for each of the chosen criteria, the effects it produces. Results could be quantitative or qualitative;
- forecast of the effects of the intervention in terms of the selected criteria; from the results coming from the previous stage (both in qualitative and in quantitative terms), a score, or a normalised value, is assigned (this is the equivalent of ‘money’ in S-CBA);
- identification of the typology of subjects involved in the intervention and the determination of respective preference functions (weights) accorded to different criteria;

- scores under each criterion are then aggregated (simply with a sum or with a non-linear formula) to give a numerical evaluation of the intervention; the result can then be compared with the result for other similar interventions.

Computable general equilibrium models

In simpler terms, General equilibrium theory or Walrasian General Equilibrium assumes “the current equilibrium prices are those at which the demand and the supply of each service or product are equal and at which, moreover, the price of each product is equal to the average cost resulting from the productive services used. [21]” This field of economics focuses on determining prices and quantities across various interconnected markets simultaneously [22]. CGE models are based on the general equilibrium theory and are commonly used in empirical analysis to examine the overall welfare and distributional impacts of policies [23]. These models are particularly useful for policies that affect multiple markets or involve various tax, subsidy, quota, or transfer mechanisms. The United States Environmental Protection Agency (USEPA) developed and uses a version of the CGE model called SAGE (a recursive acronym for SAGE is an Applied General Equilibrium model) to aid in the analysis of environmental regulations and policies [24]. Scottish government uses a CGE model that uses economic data and equations to represent the economy and how firms, households, and the government behave. They help simulate policy changes and track their effects on income and spending [25].

Input-output models

Input-output economic models quantify the interdependencies among different sectors of an economy by mapping how the output of one industry serves as an input for another. These models utilize input-output tables (e.g., [26]) to illustrate the flow of goods and services, enabling analysis of the direct and indirect economic impacts of changes in policy, investment, or external shocks [27]. They are widely used in economic impact analysis, environmental economics, and regional planning to provide a comprehensive and quantitative understanding of the economic structure and its interconnections, though they are limited by their static nature and assumption of fixed input coefficients. The Joint Research Centre (JRC) of the European Commission uses input-output economics to analyse the economic, social, and environmental impacts of EU policies.

Integrated Assessment Modelling

Integrated Assessment Models (IAMs) represent complex physical and social systems to assess and evaluate complex issues, particularly those related to climate change and sustainability. These models integrate data and processes from different disciplines using information that focuses on the interactions between the economy, society and the environment to provide comprehensive insights into how different factors interact over time [28]. IAMs are used to predict the long-term impacts of policies and actions on the environment, economy, and society, helping policymakers make informed decisions, particularly in relation to global climate change. There are more than 20 IAMs available, varying in their complexity [29].

Macro-econometric models

Macroeconomic models are large-scale economic models often used by governments and central banks for analysis, forecasting, risk and scenario analysis, and policy simulation. These models, including Computable General Equilibrium (CGE) models and Dynamic Stochastic General Equilibrium (DSGE) models, help quantify the impact of regulatory decisions, environmental changes, and public health interventions in monetary terms [30].

Marginal abatement cost curves

Marginal abatement cost is the cost of a policy or technology intervention that reduces greenhouse gas emissions by one tonne over a given period, relative to a given baseline [31]. MACCs are usually characterised by cost, €/tCO2e abated on the y-axis and abatement potential, kt CO2 e/year on the x-axis, and different abatement options are plotted as bar plots. The height of the bar represents the cost, and its width represents the abatement potential. Governments use the MACC approach to consider different policy options in different sectors of the economy [32]. While MACC models can employ different methods, including bottom-up and top-down approaches such as CGE models, to generate MAC curves, they tend to evaluate each measure separately. This approach is falling out of favour compared to long-term strategies that consider sector interactions and technological changes [33]. These strategies aim to minimize the total cost of the transition rather than focusing solely on marginal costs. Impacts can only be measured in terms of reduced greenhouse gas emissions.

Summary of decision-making frameworks

In many cases, different frameworks or modelling methods are used together to complement each other. Moreover, there are only a few holistic decision-making methods that include multiple benefits in their assessments. A summary of decision-making frameworks used for the quantification and monetisation of multiple benefits for different purposes is given in Table 1. Due to its relative simplicity and comprehensive coverage of various impacts such as health, energy, and income, the MBx tool uses **Social Cost-Benefit Analysis (SCBA)** as the basis for quantifying and monetising the social, micro-economic and environmental benefits for investment decisions.

Table 1: A mapping of methods and their use in the assessment of multiple benefits with strengths and limitations [34]

Methods	Climate	Health	Ecosystem	Crops	Energy system	Built environment	Social welfare	Macro-economic	Resources	Strengths	Limitations
Cost-Benefit Analysis	X	X	X	X	X	X	X	X	X	Analytical rigour, expresses all impacts in a single unit, applicable to all environmental impacts and a few social ones	Intended for small-scale projects, methodological constraints to monetisation, ethical considerations
Life Cycle Assessment	X	X	X	X	X	X			X	Assesses upstream and downstream impacts	No theoretical basis for a single score, no consideration for economic feedback
Multicriteria Analysis	X	X	X	X	X	X	X	X	X	Wide applicability, can engage stakeholders in the	Subjective weighing with a limited scientific basis

										process, no monetary evaluation	
Computable General Equilibrium models								X		Ability to model the entire economic impact	Market-focused and do not account for external impacts
Input-Output models								X		Focus on the entire economy	Simplified view of economy
Integrated assessment models	X	X	X	X		X			X	Links between economy and environmental systems	Lack of consistent theoretical framework
Macro-econometric models								X		Focus on the entire economy	Too complex and lack a comprehensive view
Abatement cost curves	X	X	X	X	X	X	X	X	X	Costs of energy savings and emissions abatement (direct)	No interaction with the economic system

3. Methods for attaching values (monetisation) to multiple benefits

Assessment of valuation

Use and non-use values

The monetary measure of the change in individual well-being due to a change in environmental quality is called the total economic value of the change. The total economic value of a change or resource can be divided into two categories: use values and non-use values. The total economic value can therefore be expressed as the sum of these two categories, i.e.,

total economic value = use values + non-use values

- **Use value:** The term "use value" refers to the value that individuals derive from the current or future utilisation of a good. This encompasses activities such as recreation and productive activities, including agriculture and forestry. Additionally, it encompasses the indirect benefits derived from the ecosystem services that are utilised by an economic agent. An example of this would be the purification of drinking water by the soil. These values can be categorised as "actual", "option" and "indirect" values. In this context, uncertainty arises from a combination of two factors: the individual's uncertainty about future demand for the resource and uncertainty about its future availability.
- **Non-use value**: It can be assumed that each individual places a value on the well-being produced by the existence of the good, both for oneself (**existence value**) and for other individuals, either in the same generation (**altruist value**) or future generations (**bequest value**). This is called non-use value. Non-use values are less tangible than use values since they do not refer to a physical consumption of goods and services.

Values are directly linked to the ecological services provided by the ecosystems that support them. A reduction in the provision of ecological services (e.g. as a result of pollution) is likely to reduce the values that people place on environmental quality, with a consequent reduction in social benefits. It is important to recognise that economic value does not directly value environmental quality per se, but rather reflects people's preferences for that quality. The valuation is 'anthropocentric' in that it is based on people's preferences. Figure 1 illustrates some of the main valuation methods.

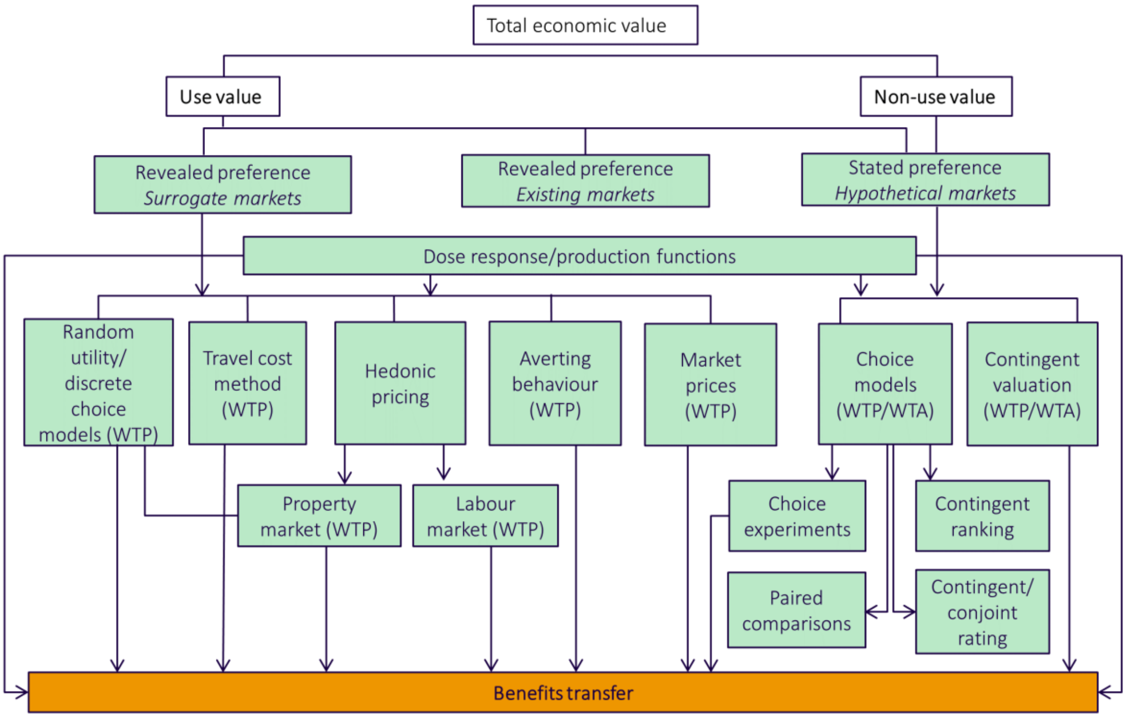


Figure 1: Main valuation methods [35]

Willingness to pay (WTP) and willingness to accept (WTA)

The majority of valuation methods are based on one or both of two fundamental approaches, namely the individual's willingness to pay (WTP) and/or willingness to accept (WTA). Together, both these approaches can be usefully applied to quantify both the direct benefits and the positive or negative impacts of the project's externalities. The WTP is defined as the maximum amount that individuals are willing to pay to gain outcomes that they consider desirable, or alternatively, the maximum amount that individuals are willing to pay to avoid outcomes that they consider undesirable. The WTA represents the minimum amount of money that the seller would be willing to accept to give away the good.

Empirical evidence shows that people tend to give higher estimates of WTA than of WTP. This is because people tend to demand higher monetary compensations for giving up goods they already possess, than the price they say they would be willing to purchase the same good they do not currently have. Therefore, the literature recommends the preferable use of WTP [36]. Consequently, the next sections will primarily focus on the concept of WTP, which is commonly used in the context of CBA. The importance of using the WTP approach is even similarly evident when externalities, for which no monetary compensation is paid, are generated by the project. The externalities have to be 'internalised', i.e., valued in monetary terms and incorporated into the economic analysis of the project. For both positive and negative externalities, the WTP in most cases provides a reference estimate of their social value. This allows estiamating the total welfare improvement to be valued, taking into account welfare changes for all gainers and losers of the project.

Methods of valuation

Market-based valuations

Market-based valuation is used to determine the value of assets based on recent sales prices of similar assets [37]. This approach is useful and possible when there is sufficient and comparable public data on sales, for example, in publicly traded shares and real estate. Usually, adjustments are made to the actual comparatives based on certain factors that differ significantly. For example, the year of construction or amenities can make a big difference to the value of a property in the same area.

Revealed preference methods

Revealed preference methods derive statistical inferences about values based on the actual choices people make in markets [38]. These methods are particularly useful for uncovering the value of various implicitly traded environmental goods and services [35]. Some of these methods include the hedonic price method, the travel cost method and the averting behaviour and defensive expenditures method. The hedonic price method observes behavioural preferences, particularly in the property and labour markets, to determine the demand for differentiated products and has applications in determining the value of environmental quality, health and mortality risks [35]. Similarly, the travel cost method estimates the recreational value of non-market goods. The averting behaviour and defensive expenditures method observes behaviour related to time costs, and purchases to avoid harm, e.g. investing in goods and services that ensure health, safety and well-being.

Stated preference methods

Stated preference approaches are survey-based and elicit people’s intended future behaviour in the markets. Through an appropriately designed questionnaire, a hypothetical market is described where the good in question can be traded. A random sample of people is then asked to express their maximum willingness to pay for (or willingness to accept) a supposed change in the good’s provision level. The main strength of the methods based on this approach is represented by the flexibility they can assure. Indeed, they allow the evaluation of almost all non-market goods, both from an ex-ante and an ex-post point of view. Moreover, this methodology can capture all types of benefits from a non-market good or service, including the so-called non-use values. The main specific methods are:

- contingent valuation method
- choice modelling method

Contingent valuation

The aim of the contingent valuation method is to elicit individual preferences, in monetary terms, for changes in the quantity or quality of a non-market good or service. The key element in any contingent valuation study is a properly designed questionnaire. The questionnaire aims to determine individuals’ estimates of how much having or avoiding the change in question is worth to them. To conduct a contingent valuation, it is worthwhile:

- investigating the attitudes and behaviour related to the goods to be valued in preparation for answering the valuation question and to reveal the most important underlying factors driving respondents’ attitude towards the public good;
- presenting respondents with a contingent scenario that provides a description of the commodity and the terms under which it is to be hypothetically offered. The final questions should aim to determine how much they would value the good if confronted with the opportunity to obtain it under the specified terms and conditions;

- asking questions about the socioeconomic and demographic characteristics of the respondents to check the extent to which the survey sample is representative of the population involved;
- asking respondents whether they would be willing to pay a specified amount for the good; if the answer is affirmative, the interviewer would repeat the questions by slightly increasing the price until the respondent expresses an unwillingness to pay the amount specified.

At the end of the survey process, analysts use appropriate econometric techniques to derive welfare measures, such as mean or median willingness to pay and to identify the most important determinants of willingness to pay. Regarding the statistical indicators to be used, the median could be the best predictor of what the majority of people would be willing to pay because, unlike the mean, it does not give much weight to outliers. Problems with contingent valuation are associated with the probability that respondents do not fully understand the scenario or what the good in question is, or that they are not willing to attach a monetary value to certain goods (such as, for example, the value of a human life). Additionally, Carson and Groves [39] point out that an increase in the provision of a public good for which only voluntary contribution is asked is generally overvalued: this is because respondents have an incentive to free-ride to increase the chances of provision of the desired good without having to pay for it.

Choice modelling

Choice modelling (CM) is a survey-based method for modelling preferences for goods when goods are described in terms of their attributes and the level of these attributes. Respondents have various alternative descriptions of a good, differentiated by their attributes and levels, and are requested to rank the alternatives, to rate them or to choose their preferred option. By including price/cost as one of the attributes of the good, willingness to pay can be directly recovered from people’s rankings, ratings or choices. Also, in this case, the method allows the measurement of non-use values.

Subjective well-being and life satisfaction methods

Individual subjective well-being is a measure of how life is perceived and experienced by individuals [40]. Subjective well-being (SWB) is studied in various disciplines, including philosophy, economics, psychology, public health and human ecology [41]. SWB can be used as a predictor of other outcomes or as an outcome itself, e.g. SWB as a proxy for health status assessment or the impact of public parks on SWB. Various national statistical offices are now collecting data on SWB [42]. Studies show that, among other factors such as income level, marital status and health, the natural and physical environment has a strong impact on SWB [42]. As a valuation technique, it is relatively new compared to revealed or stated preference methods and provides an alternative way of valuing non-market changes; and SWB can be used to estimate direct monetary measures of welfare change and can be used to assess the valuation of changes in health and the environment, such as air quality and noise [35].

Benefit transfer method

Developments in policy behaviour have stressed the relevance of the so-called benefit transfer approach (or method) in the appraisal of non-market goods, specifically environmental goods and services [35]. This method consists of taking a unit value for a non-market good estimated in an original study and using this estimate, after some adjustments, to value benefits (or costs) that arise when a policy or project is implemented elsewhere. The benefit transfer method can be defined as the use of a good estimate in one site, the ‘study site’ as a proxy for values of the same good in another site, the ‘policy site’. For example, the provision of a non-market good at a policy site could refer to a lake at a particular geographical location. If sufficient data is not available for that country, analysts can use values for similar conditions in data-rich countries.

The interest shown in this approach is due to the opportunity to reduce the need for costly and time–consuming original studies of non-market goods values. Moreover, benefit transfer could be used to assess whether or not a more in-depth analysis is worthwhile.

Benefit transfer is usually performed in three steps:

1. compilation of the existing literature on the subject under investigation (recreational activity, human health, air and water pollution, etc.);
2. assessment of the selected studies for their comparability (similarity of the environmental services or benefits valued, difference in revenue, education, age and other socioeconomic characteristics which can affect the evaluation);
3. calculation of values and their transfer in the new context of evaluation.

4. Calculation approaches for quantifying and monetising the multiple benefits of SPENS

Identification of multiple benefits or end-point impacts of SPEN clearly are critical for decision-making. These must follow a methodological approach as it has been demonstrated in *D5.3 Multiple benefits of sustainable plus energy neighbourhoods and their potential impact on policy and investment decisions using an impact pathway approach*. After the identification of these impacts the process to quantifying them and monetising them must be followed using methodologies as described in the Section 3 above. Some of the benefits of SPENs can be measured and monetised, while others are not easily quantifiable. However, for the development of the MBx tool only quantifiable impacts were detailed and included in the impact database of the tool. The tool uses these impacts to conduct the social cost benefits analyses (S-CBA) as described in Section 2. The SCBA methodology gives the estimated Return-on-investment or Benefit cost ratio as the main decision-making parameters for relevant stakeholders.

All the impacts presented in this section have been included in the MBx Tool and their detailed calculations for quantification and monetisation have been presented here. **However, it is important to note that the monetisation values have been (in some cases) derived from case studies from different countries and may not be representative for other countries, therefore, a careful examination must be conducted at national level to derive similar values using the methods described in this section or corresponding literature.**

Property value increase per dB noise reduced

Road traffic noise is generally continuous and long-term exposure can have significant adverse effects, mainly due to stress-related factors. While the untrained ear can generally only detect differences in noise levels of three decibels (dB) or more, smaller increases will still affect people's wellbeing. There is considerable evidence to show that noise can cause adverse health effects in people, such as sleep disturbance and speech interference, and psychological impacts such as annoyance reaction and other behavioural impacts [43]. These can be categorised as disruptive impacts. Environmental Noise Directive (Directive 2002/49/EC) address the issue of environmental noise pollution levels in the EU [44].

SPENs must comply with the regulatory requirements for average noise design levels for residential buildings and facilities. There are several options for reducing the effects of road traffic noise. These include the provision of barriers, building insulation and alternative road surfaces. These measures add value to the project and could increase property values.

Quantification and monetisation

The methodology for valuing the impact of noise at sensitive sites should be appropriate to the site. For example, willingness-to-pay surveys may be appropriate for sites with high concentrations of pedestrians, but inappropriate for hospital sites. One study showed that the benefits of noise mitigation increased property value by 10-12% [45]. Another European study estimated that the cost-benefit ratio of implementing the Environmental Noise Directive would be 1:29 [46]. The MBx tool considers the value of noise abatement on sites to be 10% of the value of the property, which is a reasonable figure for the EU. Using an average value [47] of the property (e.g., an apartment) of €210,000 and an occupancy of 2.2 persons (EU census data [48]), **the MBx tool estimates the value of mitigating noise as €21,000 per property and €9,545 per resident affected by this measure**. This figure should be applied to all areas, as there is no reason to believe that noise is less annoying to people in areas with low house prices. It is debatable as to what range of noise increase the cost should be applied to, but a conservative approach would be to apply it to any increase above the existing ambient noise. This reflects a belief that most people dislike noise increases, even if the resulting noise is less than 55dB, beyond which Environmental Noise Directive makes it necessary to identify the contours of noise levels.

Increase in household disposable income (reduction in energy poverty)

Disposable household incomes in SPENs can be increased through energy efficiency in space heating, hot water generation or energy-using appliances, such as refrigerators or televisions, as the vast majority of the measures implemented are cost-effective [49]. Initial investments in energy efficiency for the renovation of buildings usually pay for themselves, for example, in the form of reduced heating costs, allowing consumers to spend their money elsewhere in the long run. However, as the evaluation of the German KfW Energy-efficient Refurbishment Programme emphasizes, these investments only pay for themselves after a period of several decades [50]. Taking energy-using products as an example, the net financial savings from full implementation of the Ecodesign Directive, which sets minimum efficiency requirements for these products, are estimated at 332 EUR per household per year in Europe [51].

However, rebound and spillover effects must be considered as well. These are a direct result of positive economic outcomes such as increases in real incomes. In addition, potential energy savings may not be realised due to behavioural changes, such as increased consumer access to energy-consuming appliances and to higher levels of comfort (e.g. through higher indoor set-point temperatures). Estimates of the reduction in energy savings due to rebound effects range from 1% to 30% [52]. The magnitude varies by sector, location and time, but should be taken into account by policymakers [53].

Quantification and monetisation

To calculate the effect of energy saving on the disposable incomes of households we use the following formula:

$$\Delta INC_E = [INC_E^0] - [INC_E^1] = INC_E^0 - [INC_E^0 + (ec * ES_{HH})]$$

where,

INC$_E$ represents the share of energy costs in the disposable income of households with (1) and without energy savings (0);

ec the cost per energy unit; and

ES$_{HH}$ is the energy savings per household.

ΔINC_E provides the change of the share of energy costs in the disposable household income in percentage points [%p] for an average household of the respective country.

To determine the impact of energy efficiency on the financial situation of low-income households, the effect of energy costs saved through energy efficiency on the disposable income of households in the first income quantile (i.e. below 11,700€ of household income for the EU28) is considered. The average EU monetary savings per household due to energy savings recorded in 2019 using the above methodology is €300 per year [54]. Therefore, in the MBx tool, we consider the increase in household disposable income due to energy efficiency improvements as €300 per year.

To illustrate this with the help of an example, let us assume that the pre-intervention level (i.e., before the renovation) is 0 i.e. €0 per household per year (meaning no energy savings) and we assume that the post-intervention level is 1.0 i.e. €300 after the renovation/move into better building. Therefore, we assume that if residents move into better rated buildings, the disposable income will increase.

Increased rents (WTP for energy efficiency)

SPENs would create better buildings and neighbourhood environment, which results in increased rents for these buildings due to their increased energy efficiency. There is a direct relationship between increased rents with energy efficient buildings as highlighted in the literature [55].

Quantification and monetisation

The improved energy efficiency has a price premium on the rents and the willingness to pay (WTP) method would determine the feasibility of renting such buildings. Therefore, the framework of choice contingent valuation method (CVM) is used to estimate tenants' willingness-to-pay. In this method (1) a survey is used to ask questions such as 'how much are you willing to pay per month for an increase in energy efficiency from class D to class A?'. Such questions capture willingness on a given scale [56]. (2) Hedonic regression is used to determine the willingness to pay for energy efficiency in housing markets. However, this value is highly dependent on spatial factors [57]. Some key issues to consider in the assessment of rent increases are:

- WTP for renewable technologies is higher than for energy efficiency
- WTP varies across a city, so, spatial factors are crucial to consider
- Rising rents could be due to dynamic market development and sometimes independent of energy efficiency improvements

Based on a hedonic regression study carried out in Wuppertal, Germany, **the MBx tool estimates the net rental increase due to energy efficiency improvements to be between €0.14 and €0.18/sqm/month** [58].

$$\ln(price_i) = \alpha + \beta EE_i + \gamma H_i + \delta N_i + \mu T_i + u_i$$

$$u_i = \lambda w^i * u_j + \varepsilon_i$$

where,

$\ln(price_i)$ = Rental price per square meter (€),

α = Constant,

βEE_i = Energy performance of the apartment based on energy performance certificate (EPC) measured in kWh/square meter/annum,

γH_i = Housing/apartment characteristics (e.g., floor, fitted kitchen, building age, living space, etc.),

δN_i = Neighbourhood characteristics (e.g., population density unemployment rate, etc.),

u_i = Time dummy.

One hour citizen compliance burden - cost of an individual's time

One hour citizen compliance burden captures the cost of compliance of an individual's time with public authorities/government processes e.g. for filling in the forms, making applications etc. **SPEN communities are constructed on the basis of collective action and require the involvement of residents to function effectively**. Consequently, it can be assumed that citizens would be required to participate or manage certain additional aspects in comparison to business-as-usual.

Quantification and monetisation

1 hour citizen compliance burden is calculated by multiplying the average ordinary time hourly earnings by 40 hours multiplied by 52 weeks (net wage) per hour. **Based on the labour costs in the European market, MBx tool estimates the value of 1 hour citizen compliance burden as €30 per event** [59].

Physical health gain from walking and cycling

Facilities for safe walking and cycling as a mode of transport can lead to physical health benefits. SPENs improve/provide a location (e.g. a dedicated pathway) for safe walking and/or cycling, thereby providing a health benefit to the pedestrians and cyclists who use this infrastructure. The impact relates to people changing their mode of transport from private car to walking or cycling, and therefore becoming more active.

Quantification and monetisation

Walking

The value of the health benefits of walking is calculated by multiplying the average walking distance of 1km times the value of health benefit per user per one hour per week shown in Table 2 below. However, the annual benefit calculated for each new individual pedestrian cannot exceed the maximum annual benefit [60]. **The MBx tool puts the value of the health benefits of walking at €6,420 per year**.

Table 2: physical health gain from walking

Benefit	Health benefit for new/ existing user (1h/week)	Maximum annual benefit per new/ existing user
Pedestrian	€120.00	€6,240

Cycling

A benefit of €0.98 per kilometre (for regular bikes) and €0.22 per kilometre (for e-bikes) can be attributed to the cyclists using the facility due to improved physical health outcomes [61]. The annual health benefit can be calculated by multiplying an average distance in both directions per user (i.e., length of the trip) by the total number of weeks per year (i.e., 52) by the value of the health benefit. However, the annual benefit calculated for each new cyclist cannot exceed the maximum annual benefit of €917/year, which is the total estimated economic health benefit for converting an inactive person into an active person either using conventional cycling or electrically assisted cycling. An example assumption of the impact for an e-bike is shown in Table 3 below:

- An average two-way distance cycled per user: 6km
- Cycling specific number of days per week for 52 weeks per year
- €0.98 per kilometre (for regular bikes) with €917/user/year cap on the health benefit benefits

Table 3: physical health gain from cycling

Days cycled/week	Annual health benefits from e-bike (Days cycled/week*52 (weeks per year))*0.98 (€)
1	€305
2	€611
3	€917

The MBx tool puts the value of the health benefits for each new cyclist of cycling at €917 per year.

Health loss from air emissions (PM10, NOx, CO, Hydrocarbons)

Air pollution leads to health losses in the form of respiratory diseases. Air emission of different particles and gases, like PM10, NOx, CO and Hydrocarbons have significant health effect on the population. All of these compounds are associated with respiratory diseases, besides that some of them either impair cognitive functions or induce cardiovascular issues [62], [63], [64]. **Associated with respiratory diseases, cardiovascular issues, and impaired cognitive functions. The following are some major pollutants.**

- **Particulate matter** (PM2.5 – matter that is 2.5 microns (µm) or smaller), which predominantly impacts on respiratory and cardiovascular systems. Effects can range from reduced lung function, to increased medication use and increased hospital admissions, right through to reduced life expectancy and death.
- **Nitrogen dioxide** (NO2), a gas that causes increased susceptibility to infections and asthma. It reduces lung development in children and has been associated with increasingly more serious health effects, including reduced life expectancy.
- **Carbon monoxide** (CO), a gas that is readily absorbed from the lungs into the bloodstream. It attaches more readily to haemoglobin in the blood than oxygen, causing headaches, dizziness and weakness. It can also aggravate heart conditions.
- **Volatile organic compounds**, hydrocarbons that include a wide range of chemicals, some of which are carcinogenic to humans. Volatile organic compounds can also react with NOX (nitrogen oxide and NO2) in the presence of sunlight to form ozone (O3), which is a lung irritant.

Improving energy efficiency in buildings and neighbourhoods will also improve indoor and outdoor air quality. Improving energy efficiency in buildings and neighbourhoods will also improve indoor and outdoor air quality. **SPENs will lead to improved health outcomes for their inhabitants. This leads to improved health outcomes and a reduction in the incidence of various diseases, such as respiratory diseases**.

Quantification and monetisation

Even though, sick leaves in EU are often fully paid until a certain number of sick leaves per year, if this number of sick leaves passes the prescribed time (varying from country to country, e.g., in Austria this is 6 weeks in the first work year) there is a 50% pay cut for every additional day.

For calculation the avoidance of income loss due to absence, this 50% pay cut is taken into account with the average salary. Avoidance of loss of income due to absence from work is thus calculated as follows:

Avoidance of loss of income due to absence of work = Reduced number of sick days due to avoidance of associated diseases * Average daily wage of person * 0.5

Table 4: Example showing monetisation of avoidance of loss of income due to absence from work due to illness

Parameter	Value
Number of sick days avoided per person due to associated diseases	5.1
Average daily wage per person (Austria)	€126.1
Avoidance of loss of income due to absence from work	5.1x126.1x0.5= €322 per person

Reduction in hospital visits

SPENs will lead to improved overall health outcomes for their inhabitants. This results in a reduction in the number of visits to the hospitals, both for the inpatients and outpatients.

Quantification and monetisation

In-patients

The quantification for the reduction in the number of visits for inpatients is based on an average taken from data in Germany for each in-patient treatment [65], [66]. **MBx tool assumes an amount of around €5,000 per visit could be saved on hospital visits due to improved health outcomes in SPENS.**

Out-patients

The costs of outpatients are obtained from the Eurostat healthcare statistics. **Each outpatient visit costs about €80 per visit.**

GP visits reduce

SPENs will lead to improved health outcomes for their inhabitants. This results in a reduction in the number of visits to the General Practitioner. This results in the reduction of expenditure on both public and private healthcare in the form of Government contributions for healthcare and the patient co-payment for healthcare.

Quantification and monetisation

Publicly funded (Government contribution) reduce- description and units

The average number of consultation visits to a doctor in the EU ranges from 4 to 7.3 per year [67]. Improvements in energy efficiency have a direct impact on the number of visits to the doctor. Each GP visit costs a certain amount per inhabitant in terms of public expenditure. The frequency of consultations also depends on socio-demographic factors, such as age and gender. **The MBx tool assumes that €50 per consultation visit will be charged to the public expenditure.**

For example, the pre-intervention level is 6 GP visits per child per annum and we will assume that the post-intervention level is 5.7 after the renovation/move into better building. Around 5% of GP visits are due to poor indoor environment, and we will assume that if we increase renovation, these GP visits will cease.

Private funding (patient co-payment)

Similar to the public expenditure, each GP visit costs a certain amount per inhabitant in the form of private or personal expenditure. **An assumption of €40 per consultation visit is taken towards the public expenditure.**

Health and Quality life gains (Quality-adjusted life year (QALY) gained)

Quality of life improves with better health outcomes. The monetary equivalent of health gains is often expressed in Euros per quality-adjusted life years (QALYs) [68]. **SPENs will lead to improved health outcomes for their inhabitants. This results in the QALY gains**.

Quantification and monetisation

To calculate QALY gain, we have to look at specific utility. Levels of QALY gains for the avoidance of associated diseases (respiratory, cognitive and cardiovascular) is around 0.02-0.03 QALY per person. If we further utilise the ~ 5.1 days of illness per year connected to absence due to associated diseases the QALY gains can be calculated as follows:

QALY gains = 1/365* Avoided number of absences in a year * Average QALY gains

where,

Avoided number of absent days in a year	5.1
Average QALY gains	0.025

To monetize this, an average value of QALY is utilised, e.g. for Austria which is around €30,000 [69].

Monetary gains from avoidance of associated diseases are calculated as = QALY gains * Average value of QALY

For the MBx Tool, an average median value of €40,000 for the EU has been taken.

Value of a Statistical Life Year (VSL)

The Value of Statistical Life (VSL) is a measure used to quantify the benefit of reducing the risk of death. It represents the monetary value placed on a small reduction in the risk of death by a population. This concept is used in cost-benefit analyses to evaluate the economic impact of policies, regulations, and projects that aim to improve safety, health, and environmental conditions [70]. **SPENs will lead to improved health outcomes of their inhabitants. This results in the VSL gains**.

Quantification and monetisation

$$VSL = \sum_{0}^{t} \frac{VOLY}{(1+d)^t}$$

Where,

t = life expectancy and d is discount rate (OECD)

$$VSL_{i,2025} = VSL_{EU28,2011} \times \left(\frac{GDP_{i,2011}}{GDP_{EU28,2011}}\right)^{0.8} \times PPP_{2011} \times (1 + \Delta P_{2015-2011}) \times (1 + \Delta GDP_{2015-2011})^{0.8}$$

where

i = country in consideration

GDP = gross domestic product

PPP = purchasing power parity

P = inflation

0.8 = income elasticity

The economic values used to represent value life years and statistical life are naturally associated with uncertainties, and many parameters affect the values. Remaining life expectancy, quality of life, as well as economic resources, vary over a lifetime, and all affect stated or revealed values of life-years and statistical lives. Correspondingly, results often have a wide uncertainty range. For e.g. the standard value of a life year (VOLY) and VSL approaches to valuation of life-shortening from air pollution differ since the life years lost from air pollution typically is around 11 years [71], which is lower than the halved life expectancy typically associated with VSL studies. In detail, the VOLY method is based on life tables: it takes into account at what age people die from air pollution and gives results in terms of life expectancy. The VSL method does not use life tables, instead operating with mortality rates. As the VSL method does not consider age or death reasons, it is sometimes considered to be overestimating health benefits from air pollution reduction [72], while the VOLY approach is more conservative. However, the VOLY approach is criticized for not valuing vulnerable populations as high as average populations. VSL is thus widely used in Cost-Benefit Calculations [73].

The MBx tool considers the average value of the VSL for the EU as €158,448 per year [74]**.**

Discount on insurance premiums increase

Due to improved and better building construction, there is a reduced risk of water flooding, fire, damage, cracks etc. Financial protection is key for owners and tenants in such a situation. **SPENs are therefore expected**

to reduce insurance premiums and improve insurance ratings due to better and safer infrastructure. Factors such as advanced construction, micro-grids, solar photovoltaics, wind energy, energy efficiency, and energy storage provide better value and protection against risks.

Quantification and monetisation

Some policy providers reduce their insurance premiums if the policy holder does not claim for damages from 3-5 years with up to 10%. Thus, savings of 10% could be assumed for the owners due to SPENs.

Average property insurance premiums range around €224 per annum (2022) in Germany. **The MBx tool assumes a discount of 10% on the premium due to SPENs, which is approximately equal to €22 per year, based on the study in Germany** [75].

House condition: minor problems (maintenance) reduced

Living in a dwelling with high architectural quality, a well-designed energy system and a common energy management facility can reduce individual maintenance costs compared to standard households [76]. **SPENs usually have these features and therefore lead to a reduction in the maintenance costs of dwellings due to minor problems**.

Quantification and monetisation

The cost of reducing minor problems through SPENs can be calculated as follows:

12 (no. of months) * difference in €/m2 monthly maintenance cost between newly built SPEN and standard house * average area of the dwelling in m2.

The MBx tool considers this value to be €1,836 per property (i.e., per multi-family dwelling).

Occurrence of diseases – Cost-off-illness methodology

SPENs will lead to improved health outcomes for their inhabitants. This results in improved health outcomes and a reduction in the occurrences of various diseases, such as respiratory diseases, circulatory and cardiovascular diseases (hypertension, stroke and heart attack) and mental health illnesses.

Quantification and monetisation

The basic aim of cost-off-illness studies is to identify and measure all the costs of a disease. They describe and estimate the economic burden of a particular disease on a society, and therefore the savings that could be made if the disease were to be eliminated. Cost-off-illness studies are used to [77] (1) define the magnitude of the disease or injury in monetary terms; (2) justify intervention programmes; (3) assist in the allocation of research investments to specific diseases; (4) provide a basis for policy and planning in relation to prevention and control initiatives; and (5) provide an economic framework for programme evaluation.

To calculate the cost-of-illness (COI), it is necessary to recognise, identify, list, measure and value the costs that a disease and its comorbidities can generate [77], [78]. Cost-of-illness studies have traditionally stratified costs into three categories: direct, indirect and intangible costs. However, due to the difficulties in measuring and estimating the intangible costs, most of the studies include only the direct and indirect costs.

- Direct costs consist of healthcare costs and non-healthcare costs. Healthcare costs are defined as the medical care expenditure on diagnosis, treatment, and rehabilitation, etc., while the non-healthcare costs are related to the consumption of non-healthcare resources, such as transport, household expenditure, relocation, loss of property, and informal care of all kinds.

- Indirect costs are the equivalent costs of the patients' productivity losses, including absenteeism from work due to doctor visits, sick leave and hospitalisation, as well as early retirement and unemployment directly related to the disease.

COI studies can be conducted from several different perspectives, each of which includes slightly different cost elements, to produce a wide range of results for the same disease. The societal perspective is the most comprehensive because it includes all direct medical costs and indirect costs for all members of a given society in which they are involved.

In the current work, only direct costs are considered from a societal perspective, and indirect costs are not included to avoid possible overlap with different impacts considered in the MBx tool.

Morbidity and mortality can be estimated using non-market values such as the value of statistical life (VSL) or the value of a life year (VOLY). They can also be estimated using market values, such as the average cost of treating a serious illness, loss of productivity, and cost of medication. Non-market estimates are more suitable for monetisation because the data are more readily available than market-based values.

To derive the monetised values for different diseases, a study has been conducted by the authors to compare the health conditions of people living in energy-efficient households with people living in non-efficient households. The work has been done using data from Barcelona from three georeferenced data sources: Barcelona Health Survey for 2016, Cadastre, and building typology characterization of the "Energy, Climate Change and Air Quality Plan of Barcelona 2011-2020". Using the database, a statistical analysis has been done to calculate the prevalence ratio of different health diseases for two groups of data: efficient households and non-efficient households. For those health outcomes that the difference amount groups are statistically significant, meaning that the non-efficient group has a higher prevalence than the efficient households, it has been calculated the Population Attributable Risk percent (PAR%). PAR% can be interpreted as the proportion of negative health outcomes in the population that is attributable to non-efficient households and that, theoretically, could be prevented by improving the energy efficiency of households. The health outcomes that present relevant results are asthma, migraine or frequent headaches, poor mental health and poor self-reported health. The prevalence rate and the PAR% have different magnitudes among men and women. Once the PAR% is obtained for those health outcomes that can be affected by the efficiency of the households, it is possible to calculate the number of women and men that will avoid having a health disease, and consequently the economic savings for the healthcare system. The associated cost related to a disease has been obtained by applying the methodology of cost-off-illness. Based on some reference studies and own calculations, MBx tool estimates the reduced cost of illness for various diseases as shown in Table 5 below:

Table 5: Types of diseases and monetised values

Type of disease	Disease	Monetised value (€)	Unit
Occurrence of respiratory diseases reduced	Asthma	1243 [79]	Per patient and per year
	Chronic obstructive pulmonary disease	1646 [80]	Per patient and per year
Occurrence of circulatory diseases reduced	Hypertension	1515 [79]	Per patient and per year
	Stroke	8491 [81]	Per patient and per year
	Heart attack (myocardial infarction)	1498 [79]	Per patient and per year
Occurrence of mental health illness reduced	Poor mental health	1080 [79]	Per patient and per year
	Migraine or frequent headaches	1533 [82]	Per patient and per year

Vacancy costs

Vacancy costs tell an investor how much potential rental income is being lost because the unit is empty and waiting for a new tenant. This depends on the vacancy rate. On average, 15.8 % of the dwellings in the EU-28 remained vacant [83]. **SPENs help to reduce vacancy rates and increase tenant demand by making features, such as energy efficiency and improved indoor environmental quality more attractiveness to tenants.**

Quantification and monetisation

The following example illustrates the concept of vacancy costs and loss of potential rental income.

Vacancy rate for a rental property portfolio with a 3-unit multifamily homes (MFH) and four single-family homes (SFH):

Vacancy rate = Number of vacant days / Number of rental days

- MFH 1: 0 days vacant / 365 rental days = 0% vacancy rate
- MFH 2: 10 days vacant / 365 rental days = 2.7% vacancy rate
- MFH 3: 31 days vacant / 365 rental days = 8.5% vacancy rate
- SFH 1: 0 days vacant / 365 rental days = 0% vacancy rate
- SFH 2: 18 days vacant / 365 rental days = 4.9% vacancy rate
- SFH 3: 20 days vacant / 365 rental days = 5.5% vacancy rate
- SFH 4: 40 days vacant / 365 rental days = 11.0% vacancy rate
- Average portfolio vacancy rate across 7 units = 4.7%.

Assuming, an average monthly rent of €1,200 per unit,

- Gross potential rental income = 7 units x €1,200 per month x 12 months = €100,800
- Vacancy costs = 4.7% x €100,800 = €4,738
- Effective gross rental income = €100,800 gross potential rental income – €4,738 vacancy costs = €96,062

While the project costs and rental units would vary from project to project, it is reasonable to assume that due to the SPEN and the demand for better and energy-efficient buildings, the vacancy rate will remain approximately lower, say as 0.5%, meaning that a gain of 4.2% over the gross potential rental income can be expected. **The MBx tool considers this to be €4,233 per project/year.**

Employment (cost per employee) increase

The construction and renovation of buildings in SPENs will create new jobs in the construction sector [84]**.** Job creation is often reported in different terms, such as gross jobs, direct jobs and indirect. The energy savings generated by SPENs redirect spending away from the energy industry to support jobs while feeding it back into the local economy. In other words, a net increase in jobs from SPENs is the result of two major changes: (1) an initial expenditure or effort that drives the SPENs savings, (2) the subsequent adjustment in consumption patterns brought about by that initial expenditure [85].

Quantification and monetisation

The following example illustrates the concept of employment (cost per employee) increase.

A developer decides to invest €10 million to build SPENs, which brings energy efficiency and other benefits to buildings and their owners. These improvements will save the city €1 million per year over the next 20 years.

This investment will create three types of jobs. First, a contractor will hire workers to carry out the desired energy efficiency measures. These contractor jobs are direct jobs resulting from the investment in the local economy. In addition, the workers will require materials that they will purchase from other companies (e.g. insulation, tools etc.). These purchases create jobs in the local economy for manufacturers and service providers. These supply chain jobs are the indirect jobs resulting from the investment. Finally, workers in these direct and indirect industries may choose to spend their earnings on goods and services in the local economy, creating indued jobs. For every €1 million invested in the energy renovation of buildings, an average of 18 jobs are created in the EU [86]. These are local, long-term jobs that will stimulate economic activity across the EU.

From the example, as in Table 6, we can assume that investments are channelled into the construction sector from the 'business-as-usual' spending scenario, thus, it will support approximately 200 (direct, indirect and induced) jobs per €1 million investment. In the business-as-usual scenario, 170 jobs will be created per €1 million. Thus overall, a net of 30 jobs are created in a year due to SPENs.

Additionally, SPENs would generate savings over the life of the investment, freeing up funds to support more jobs in the local economy by shifting jobs from low labour intensity (10 jobs per €1 million) to high intensity (17 jobs per €1 million) on average. We assume that the investment will save €3 million per year for 20 years, resulting in a net gain of 21 jobs per year (see Table 6 below).

Table 6: Comparison of SPEN vs BAU scenario for jobs created

Total investment: €10 million	
Option 1: SPENs	**Option 2: Business as usual (pre-SPENs)**
20 jobs per € million X €10 Million = 200 gross direct, indirect and induced jobs	17 jobs per € Million X €10 Million = 170 Gross direct, indirect and induced jobs
Result: 200-170 = 30 Net Jobs	
Long-term effect of investment	
20 years X €3 Million in savings spent in other areas X 17 Jobs per € Million = 1020 Gross direct, indirect and induced jobs over 20 years	20 years X €3 Million/ yr. on Utilities X 10 Jobs per € Million = 600 Gross direct, indirect and inducted jobs over 20 years
Result: 1020-600=420 Net jobs **21 Jobs** per year for 20 years	

The MBx tool considers the employment (cost per employee) increase to be 55,555 per year.

Supervision costs reduced (cost per sqm)

The requirements for monitoring and inspection of the housing stock are defined in laws, decrees, regulations, statues and generally accepted technical rules and standards. SPENs help to reduce the cost of monitoring through their technological advancements, such as integration with smart home and monitoring systems.

Quantification and monetisation

Every country has different supervision cost for their rented building stock. For example, inspection and supervision costs of an apartment with/ without lift costs are estimated around 0.13- 0.25€/sqm in Germany. Thus, an average cost is assumed for the calculation. **The MBx tool considers the supervision costs to be €0.2 per m2.**

Asset value (return on investment) increased

According to a study of the US Department of Energy (DOE), commercial buildings waste 30% of the energy paid for on average. This wasted energy was estimated at around 61 billion dollars in 2007. Based on a capitalization rate of 8%, a typical value used for building values, the lost asset value amounts to approximately $750 billion. Buildings with a certification of high energy efficiency generate a rent about 7 per cent higher than otherwise identical buildings and realize an increase of selling prices by 16 per cent.

Quantification and monetisation

For this indicator, we consider commercial buildings as the market value of residential buildings is less dependent on energy efficiency than on location and other factors. To estimate the changes in asset value due to energy efficiency improvements, we calculate the average savings in services related to the building itself, i.e. heating and cooling. Using the average costs per unit of energy for heating and cooling, we estimate the additional average net income. Assuming a capitalisation rate of 8%, the **change in asset value** can be calculated for the whole service sector can be calculated using the following formula:

$$\Delta AV = \frac{\sum_i ES_i * p_i}{cr}$$

Where ES_i represents the energy saving regarding energy carrier i (electricity and gas) with the price p and the capitalisation rate cr (in our case 0.08).

As a rule of thumb from the meta-studies, an increase of 3-8% in the price of residential property, and an increase of around 3-5% in residential rents compared to similar properties can be observed as a result of energy efficiency improvements [55], [87].

Assuming an average of €5,000 per sqm for house purchase and an average of €10 per sqm for rents. An average increase of 5% is assumed for residential assets and 4% for rentals. **The MBx tool considers the increase in the asset value to be €250 per m2 for house purchase and € 4 per m2 for rental properties.**

Improved rentability (improved revenue)

SPENs help to improve rentability and increase tenant demand by making features, such as energy efficiency and improved indoor environmental quality more attractive to tenants.

Quantification and monetisation

The MBx tool assumes an average value of €40/sqm for renting residential buildings [88].

Probability to default reduced (Better credit record)

A lender's credit risk, or payment default risk is the likelihood of losing money as a result of late or non-payment. Alternatively, at the individual level, the payment default risk refers to the likelihood that a borrower or other counterparty will fail to meet its payment obligations in time, i.e. by contractual terms [89]. Within the EeMAP project, the research presented theoretical evidence that owners and tenants of sustainable (energy efficient/green/better performing) buildings are less likely to default on their payments [90]. It found that the borrowers of green buildings have greater financial security, greater spending flexibility, less volatility in energy costs, and a lower risk of illness. In addition, the investment in energy efficiency improvements increased the value of the property. As a result, the risk of default is reduced. Owners of buildings in SPENs are less likely to default on loan repayments.

Quantification and monetisation

The MBx tool values the reduced probability of default at €5,309 per property [55].

Work productivity

Workforce performance can be defined as the amount of labour input per unit of time. An organization's workforce consists of all its employees. Workforce performance is often measured in terms of the quantity of labour input, but poor indoor air quality can also affect the quality of work. There are several case studies that show how indoor air quality and thermal comfort can affect a person's productivity. Employees have been found to perform better when working in deeply renovated buildings than in non-renovated buildings [91]. **Performance improvements benefit both employees and employers by increasing the efficiency of labour input, which is quantified as one of the multiple benefits of SPENs.**

Quantification and monetisation

One of the tools used to measure work performance is the "Comfortmeter" [92]. The Comfortmeter project is a collaboration between six renowned European universities and international authorities engaged in efficient, sustainable, and performance-driven office buildings, including Factor4 and KU Leuven. This tool objectively measures the subjective comfort experience of building users online. The survey asks building users about 6 aspects of comfort (thermal comfort, air quality, acoustics, lighting, individual control, and office environment & cleanliness), the impact on work performance ("productivity increase" according to "Comfortmeter" reports), and personal characteristics (age, gender, stress level, job satisfaction, etc). Based on benchmarked comfort scores of similar buildings in the "Comfortmeter" database, it proposes measures to improve the scores and ranks them according to their potential contribution to productivity. **For SPENs, the value of their benefits has been obtained from the research findings. The MBx tool estimates this value to be €362 per person.**

Additional Payments (WTP)

It is likely that people will be willing to make additional payments for renewable energy and investments in renewable and clean energy sources, as well as for the guarantee of a high quality of access to energy. These include:

- Additional Payments to support Utility investments in Renewable Energy (WTP) [93].
- Additional Payments to pay for premiums for renewable energy and improve generation of electricity (WTP) [94].
- Additional Payments to pay for renewable energy systems (RES) projects (WTP) [95].
- Additional Payments to pay for wind farm construction (WTP) [96].
- Willingness to pay a once-off payment to avoid uninterrupted power supply (Peak Period) [97], [98].

Quantification and monetisation

The MBx tool estimates the value of willingness to pay for renewable energy and investments in renewable and clean energy sources, as well as for ensuring access to uninterrupted power supply, as shown in the Table 7 below.

Table 7: willingness to pay for renewable energy and investments in renewable and clean energy sources

Reason for additional payment	Value (€)	Unit
Additional Payments to support Utility investments in Renewable Energy (WTP)	12	Per year

Additional Payments to pay for premiums for renewable energy and improve generation of electricity (WTP)	240	Per year
Additional Payments to pay for RES projects (WTP)	49	Per year
Additional Payments to pay for wind farm construction (WTP)	106	Per year
Willingness to pay a once-off payment to avoid uninterrupted power supply (Peak Period)	5	Per property

Energy savings – cost reductions through energy savings

Quantification and monetisation

New construction:
To evaluate the energy savings of a new building, a reference is needed. The reference is the energy demand of the reference building according to the national building code. The energy savings are then multiplied by the cost factor for the energy source used. The energy cost savings can then be calculated using the following equation:

$$Cost_{saving} = (E_{ref} - E_{new}) \times cf$$

where,

$Cost_{saving}$ = Cost saving comparing reference building with new constructions [currency]

E_{ref} = Energy demand reference building [kWh]

E_{new} = Energy demand new constructed building [kWh]

cf = Cost factor of energy carrier [currency/kWh]

The MBx tool estimates the energy cost savings for new buildings at €0.02 per kWh.

Renovation
To evaluate the energy savings of a renovated building, a reference is needed. The reference is the energy demand of the building in its unrenovated state (status quo). The energy savings are then multiplied by the cost factor for the energy source used. The energy cost savings can then be calculated using the following equation:

$$Cost_{saving} = (E_{sq} - E_{ren}) \times cf$$

where,

$Cost_{saving}$ = Cost saving comparing reference/status quo building with renovated building [currency]

E_{sq} = Energy demand building status quo [kWh]

E_{ren} = Energy demand building renovated [kWh]

cf = Cost factor of energy carrier [currency/kWh]

The MBx tool estimates the energy cost savings for renovated buildings at €0.05 per kWh.

Heat recovery from wastewater and exhaust air

Energy can be recovered from wastewater and heat that would otherwise leave the building without any further use. The energy efficiency of the building can be increased by using heat recovery systems for exhaust air and wastewater. The efficiency of the heat recovery determines the degree of increase in energy efficiency.

Quantification and monetisation

Wastewater heat reused

The cost savings from wastewater heat reuse is calculated using the formula:

Cost savings from wastewater heat reuse = (energy consumption status quo [kWh] * energy costs [€/kWh]) - (energy consumption with wastewater heat recovery (WWHR) [kWh] * energy costs [€/kWh])

The MBx tool estimates the value of reused wastewater heat at €0.35 per kWh.

Exhaust air heat recovery

The cost savings from exhaust air heat recovery is calculated using the formula:

Cost savings from exhaust air heat recovery = (energy consumption status quo [kWh] * energy costs status quo [€/kWh]) - (energy consumption with Mechanical Ventilation Heat Recovery (MVHR) [kWh] * energy costs [€/kWh])

The MBx tool estimates the value of exhaust heat recovery at €0.35/kWh.

Direct GHG emissions saved

Quantification and monetisation

Difference between costs for emissions from energy demand/consumption status quo and optimized.

Calculating savings and costs from direct emissions follows the same logic as the calculation of energy demand savings. A distinction must be made between new construction and renovation as explained below.

New construction:

To evaluate the emission reduction of a new building, a reference case is needed. The reference is the emissions resulting from the energy demand of the reference building according to the national building code. The emission reduction are then multiplied by the country-specific cost emission cost factor. The emission cost savings can then be calculated using the following equation:

$$Cost_{saving} = \left(E_{ref} \times ef_{ref} - E_{new} \times ef_{new}\right) \times cf_e$$

Where,

$Cost_{saving}$ = Cost saving comparing reference building with new constructed building [currency]

E_{ref} = Energy demand reference building [kWh]

ef_{ref}= Emission factor for energy carrier of reference building [t CO2-eq/kWh]

E_{new} = Energy demand new constructed building [kWh]

ef_{new} = Emission factor for energy carrier of new constructed building [t CO2-eq/kWh]

cf_e = Cost factor of emissions [currency/ t CO2-eq]

The MBx tool estimates the value of emission reductions for new buildings at €60 per tonne of CO2eq.

Renovation

To evaluate the emissions reduction of a renovated building, a reference case is needed. The reference is the emissions resulting from the energy demand of the building in the non-renovated status (status quo). The emission reduction is then multiplied by the country-specific cost emission cost factor. The emission cost savings can then be calculated using the following equation:

$$Cost_{saving} = \left(E_{sq} \times ef_{sq} - E_{ren} \times ef_{ren}\right) \times cf_e$$

where,

$Cost_{saving}$ = Cost saving comparing reference building with new constructed building [currency]

E_{sq} = Energy demand status quo building [kWh]

ef_{sq} = Emission factor for energy carrier of status quo building [t CO2-eq/kWh]

E_{ren} = Energy demand renovated building [kWh]

ef_{ren} = Emission factor for energy carrier of renovated building [t CO2-eq/kWh]

cf_e = Cost factor of emissions [currency/ t CO2-eq]

The MBx tool estimates the value of emission reductions for new buildings at €60 per tonne of CO2eq.

Increase in access to open space - per person

Quantification and monetisation

A case study from Greece using Contingent Valuation Method (CVM/WTP) to estimate the value of Green Space [99].

The MBx tool estimates the value of increase in access to open space as €73 per person.

5. References:

[1] COMBI, "combi-project.eu – Multiple Benefits of Energy Efficiency." Accessed: Oct. 04, 2022. [Online]. Available: https://combi-project.eu/

[2] MBENEFITS, "Multiple benefits of energy efficiency." Accessed: Oct. 04, 2022. [Online]. Available: https://www.mbenefits.eu/

[3] ODYSSEE-MURE, "Odyssee-Mure database for energy efficiency measures on national and EU-level." Accessed: Jun. 05, 2020. [Online]. Available: https://www.odyssee-mure.eu/publications/efficiency-trends-policies-profiles/italy.html

[4] S. Newbold *et al.*, "Benefit Transfer Challenges: Perspectives from U.S. Practitioners," *Environ Resour Econ (Dordr)*, vol. 69, no. 3, p. 467, Mar. 2018, doi: 10.1007/S10640-017-0207-7.

[5] P. Howden-Chapman, "How real are the health effects of residential energy efficiency programmes?," *Soc Sci Med*, vol. 133, pp. 189–190, May 2015, doi: 10.1016/J.SOCSCIMED.2015.03.017.

[6] S. Shnapp, D. Paci, and P. Bertoldi, "Untapping multiple benefits: hidden values in environmental and building policies," Brussels, 2020. doi: 10.2760/314081.

[7] COMBI, "Multiple impacts of energy efficiency in policy-making and evaluation D8 . 2 Policy report on COMBI results," no. 649724, 2018.

[8] M. Reuter, M. K. Patel, W. Eichhammer, B. Lapillonne, and K. Pollier, "A comprehensive indicator set for measuring multiple benefits of energy efficiency," *Energy Policy*, vol. 139, no. December 2019, p. 111284, 2020, doi: 10.1016/j.enpol.2020.111284.

[9] ODYSSEE-MURE, "EU Environmental Economic & Social multi benefits efficiency tool | ODYSSEE-MURE." Accessed: Oct. 04, 2022. [Online]. Available: https://www.odyssee-mure.eu/data-tools/multiple-benefits-energy-efficiency.html

[10] J. Thema *et al.*, “The multiple benefits of the 2030 EU energy efficiency potential,” *Energies (Basel)*, vol. 12, no. 14, pp. 1–19, 2019, doi: 10.3390/en12142798.

[11] EERAdata, “Home - EERAdata.” Accessed: Jun. 21, 2024. [Online]. Available: https://eeradata-project.eu/

[12] C. Economics, “Multiple benefits of investing in energy efficient renovation of buildings: Impact on Public Finances,” no. October, pp. 1–80, 2012.

[13] O. Banerjee, M. Cicowiez, and A. Moreda, “Reconciliation Once and for All: Economic Impact Evaluation and Social Cost Benefit Analysis,” Aug. 2017, doi: 10.18235/0000823.

[14] H. R. Varian, *Intermediate Microeconomics: A Modern Approach*. Norton, 2011.

[15] A. E. Boardman, D. H. Greenberg, A. R. Vining, and D. L. Weimer, “Cost-Benefit Analysis: Concepts and Practice,” Jul. 2018, doi: 10.1017/9781108235594.

[16] S. Sala, F. Raele, J. Cristobal-Gracia, L. Marelli, and R. Part, “Life cycle assessment for the impact assessment of policies,” 2016.

[17] DGNB, “DGNB System-New buildings criteria set VERSION 2020 INTERNATIONAL Environmental quality ENV1.1 / BUILDING LIFE CYCLE ASSESSMENT Building life cycle assessment,” 2020.

[18] UNEP and C. , T. M. , N. S. , E. E. , S. T. , R. G. S. , B. M. , V. S. , L. A. , F. M. , A. G. (eds.). Benoît Norris, “Guidelines for Social Life Cycle Assessment of Products and Organizations 2020,” 2020.

[19] M. Bruno, M. Marchi, N. Ermini, V. Niccolucci, and F. M. Pulselli, “Life Cycle Assessment and Cost–Benefit Analysis as Combined Economic–Environmental Assessment Tools: Application to an Anaerobic Digestion Plant,” *Energies (Basel)*, vol. 16, no. 9, p. 3686, May 2023, doi: 10.3390/EN16093686/S1.

[20] I. Linkov and E. Moberg, “Multi-Criteria Decision Analysis : Environmental Applications and Case Studies,” Oct. 2011, doi: 10.1201/B11471.

[21] L. Walras, D. A. Walker, and J. van Daal, *Leon Walras: Elements of Theoretical Economics*. Cambridge: Cambridge University Press, 2014. doi: 10.1017/CBO9781107585676.

[22] Gilbert.John, “General Equilibrium Analysis Part I Introduction to CGE.” 2017. Accessed: Jun. 20, 2024. [Online]. Available: https://www.unescap.org/sites/default/files/11_CGE_I.pdf

[23] I. S. Wing, “Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis,” 2004. Accessed: May 27, 2024. [Online]. Available: https://globalchange.mit.edu/sites/default/files/MITJPSPGC_TechNote6.pdf

[24] US EPA, “CGE Modeling for Regulatory Analysis | US EPA.” Accessed: Jun. 20, 2024. [Online]. Available: https://www.epa.gov/environmental-economics/cge-modeling-regulatory-analysis

[25] P. B. Dixon and D. W. (Dale W. Jorgenson, “Computable General Equilibrium modelling: introduction,” p. 1841, 2013, Accessed: Jun. 20, 2024. [Online]. Available: http://www.gov.scot/publications/cge-modelling-introduction/

[26] JRC, “Input-output economics - European Commission.” Accessed: Jun. 21, 2024. [Online]. Available: https://joint-research-centre.ec.europa.eu/scientific-activities-z/input-output-economics_en

[27] W. Leontief, “Input-output economics,” p. 436, 1986, Accessed: Jun. 21, 2024. [Online]. Available: https://global.oup.com/academic/product/input-output-economics-9780195035278

[28] IAMC, “What are IAMs? – iamconsortium.” Accessed: Jun. 20, 2024. [Online]. Available: https://www.iamconsortium.org/what-are-iams/

[29] UNFCCC, “Integrated Assessment Models (IAMs) and Energy-Environment-Economy (E3) models | UNFCCC.” Accessed: Jun. 20, 2024. [Online]. Available: https://unfccc.int/topics/mitigation/workstreams/response-measures/modelling-tools-to-assess-the-impact-of-the-implementation-of-response-measures/integrated-assessment-models-iams-and-energy-environment-economy-e3-models

[30] P. B. Dixon and D. Jorgenson, Eds., *Handbook of Computable General Equilibrium Modeling*. 2012.

[31] World Bank, “Marginal Abatement Cost Curve Analysis.” Accessed: Jun. 20, 2024. [Online]. Available: https://documents1.worldbank.org/curated/en/859881468197634735/pdf/103914-WP-P145943-PUBLIC-Dissemination-Note-Marginal-Abatement-Cost-Curve-Analysis.pdf

[32] Ministry for the Environment, “Marginal abatement cost curves analysis for New Zealand: Potential greenhouse gas mitigation options and their costs,” 2020. Accessed: Jun. 20, 2024. [Online]. Available: https://environment.govt.nz/assets/Publications/Files/marginal-abatement-cost-curves-analysis_0.pdf

[33] S. HALLEGATTE, “Proper use of the abatement cost to steer the transition - I4CE.” Accessed: Jun. 20, 2024. [Online]. Available: https://www.i4ce.org/en/proper-use-abatment-cost-streer-transition-climate/

[34] D. Ürge-Vorsatz, Á. Kelemen, M. Gupta, S. Chatterjee, M. Egyed, and A. Reith, “Literature review on Multiple Impact quantification methodologies,” no. 649724, pp. 1–49, 2015.

[35] OECD, *Cost-Benefit Analysis and the Environment*. OECD, 2018. doi: 10.1787/9789264085169-en.

[36] J. Schmidt and T. H. A. Bijmolt, “Accurately measuring willingness to pay for consumer goods: a meta-analysis of the hypothetical bias,” *J Acad Mark Sci*, vol. 48, no. 3, pp. 499–518, May 2020, doi: 10.1007/S11747-019-00666-6/TABLES/5.

[37] M. Meitner, *The Market Approach to Comparable Company Valuation*, vol. 35. Heidelberg: Physica-Verlag, 2006. doi: 10.1007/3-7908-1723-6.

[38] K. J. Boyle, “Introduction to Revealed Preference Methods,” 2003, pp. 259–267. doi: 10.1007/978-94-007-0826-6_8.

[39] R. T. Carson and T. Groves, “Incentive and informational properties of preference questions,” *Environ Resour Econ (Dordr)*, vol. 37, no. 1, pp. 181–210, May 2007, doi: 10.1007/S10640-007-9124-5/METRICS.

[40] M. Durand, “The OECD Better Life Initiative: How’s Life? and the Measurement of Well-Being,” *Review of Income and Wealth*, vol. 61, no. 1, pp. 4–17, Mar. 2015, doi: 10.1111/ROIW.12156.

[41] K. V. Das, C. Jones-Harrell, Y. Fan, A. Ramaswami, B. Orlove, and N. Botchwey, “Understanding subjective well-being: perspectives from psychology and public health,” *Public Health Reviews 2020 41:1*, vol. 41, no. 1, pp. 1–32, Nov. 2020, doi: 10.1186/S40985-020-00142-5.

[42] A. A. Stone and A. B. Krueger, “Understanding subjective well-being,” in *For Good Measure Advancing Research on Well-being Metrics Beyond GDP*, J. E. Stiglitz, J.-P. Fitoussi, and M. Durand, Eds., OECD, 2018.

[43] O. Hahad *et al.*, “Noise and mental health: evidence, mechanisms, and consequences”, doi: 10.1038/s41370-024-00642-5.

[44] “EUR-Lex - 02002L0049-20210729 - EN - EUR-Lex.” Accessed: Jun. 20, 2024. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02002L0049-20210729

[45] S. Lindgren, “A sound investment? Traffic noise mitigation and property values,” *Journal of Environmental Economics and Policy*, vol. 10, no. 4, pp. 428–445, Oct. 2021, doi: 10.1080/21606544.2021.1911861.

[46] Accon, AECOM, DG Environment (European Commission), and The Centre for Strategy & Evaluation Services LLP (CSES), “Evaluation of directive 2002/49/EC relating to the assessment and management of environmental noise,” 2016. Accessed: Jun. 20, 2024. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/7febde6d-9a89-11e6-9bca-01aa75ed71a1

[47] “Average property price by country around the world - Finder UK.” Accessed: Jun. 03, 2024. [Online]. Available: https://www.finder.com/uk/mortgages/world-cost-of-a-flat

[48] “Household composition statistics - Statistics Explained.” Accessed: Jun. 03, 2024. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_composition_statistics

[49] M. Reuter, M. K. Patel, W. Eichhammer, B. Lapillonne, and K. Pollier, “A comprehensive indicator set for measuring multiple benefits of energy efficiency,” *Energy Policy*, vol. 139, p. 111284, Apr. 2020, doi: 10.1016/J.ENPOL.2020.111284.

[50] N. Diefenbach, B. Stein, T. Loga, M. Rodenfels, K. Jahn, and J. Gabriel, “Monitoring der KfW-Programme „Energieeffizient Sanieren“ und „Energieeffizient Bauen“ 2016 ,” 2018. Accessed: Jun. 20, 2024. [Online]. Available: https://www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-alle-Evaluationen/Monitoringbericht_EBS_2016.pdf

[51] M. Smith, A. Hermlink, M. Cuijpers, E. Molenbroek, and N. Surmeli, “Benefits of Ecodesign for EU households,” Oct. 2016. Accessed: Jun. 20, 2024. [Online]. Available: https://www.anec.eu/images/Publications/Final_report_Benefits_of_Ecodesign_for_EU_households.pdf

[52] S. Sorrell, “The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency,” 2007. Accessed: Jun. 20, 2024. [Online]. Available: https://d2e1qxpsswcpgz.cloudfront.net/uploads/2020/03/the-rebound-effect-an-assessment-of-the-evidence-for-economy-wide-energy-savings-from-improved-energy-efficiency.pdf

[53] H. S. Næss-Schmidt, M. B. Hansen, and C. von Utfall Danielsson, “Multiple benefits of investing in energy efficient renovation of buildings,” 2012. Accessed: Jun. 20, 2024. [Online]. Available: https://renovate-europe.eu/wp-content/uploads/2015/10/Multiple-benefits-of-EE-renovations-in-buildings-Report-only.pdf

[54] “Enerdata Client Access.” Accessed: Jun. 20, 2024. [Online]. Available: https://clients.enerdata.net/login

[55] P. ZANCANELLA, P. BERTOLDI, and B. BOZA-KISS, “Energy efficiency, the value of buildings and the payment default risk,” *Publications Office of the European Union*, pp. 1–50, 2018, doi: 10.2760/267367.

[56] M. Collins and J. Curtis, “Rental tenants’ willingness-to-pay for improved energy efficiency and payback periods for landlords,” *Energy Effic*, vol. 11, no. 8, pp. 2033–2056, 2018, doi: 10.1007/s12053-018-9668-y.

[57] S. März, I. Stelk, and F. Stelzer, “Are tenants willing to pay for energy efficiency? Evidence from a small-scale spatial analysis in Germany,” *Energy Policy*, vol. 161, 2022, doi: 10.1016/j.enpol.2021.112753.

[58] S. März, I. Stelk, and F. Stelzer, “Are tenants willing to pay for energy efficiency? Evidence from a small-scale spatial analysis in Germany,” *Energy Policy*, vol. 161, 2022, doi: 10.1016/j.enpol.2021.112753.

[59] Eurostat, “Wages and labour costs - Statistics Explained.” Accessed: Jun. 20, 2024. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Wages_and_labour_costs

[60] A. J. Perkins and D. O. Clark, “Assessing the Association of Walking with Health Services Use and Costs among Socioeconomically Disadvantaged Older Adults,” *Prev Med (Baltim)*, vol. 32, no. 6, pp. 492–501, Jun. 2001, doi: 10.1006/PMED.2001.0832.

[61] R. Vanpée and B. Van Zeebroeck, “A comparative cost-benefit analysis of cycling within the Benelux and North Rhine-Westphalia,” 2022. Accessed: Jun. 20, 2024. [Online]. Available: https://www.benelux.int/wp-content/uploads/2023/03/Report_Cycling_Benelux_NRW.pdf

[62] M. Chandra *et al.*, “Air Pollution and Cognitive Impairment across the Life Course in Humans: A Systematic Review with Specific Focus on Income Level of Study Area,” *Int J Environ Res Public Health*, vol. 19, no. 3, Feb. 2022, doi: 10.3390/IJERPH19031405.

[63] X. Q. Jiang, X. D. Mei, and D. Feng, “Air pollution and chronic airway diseases: what should people know and do?,” *J Thorac Dis*, vol. 8, no. 1, p. E31, 2016, doi: 10.3978/J.ISSN.2072-1439.2015.11.50.

[64] B. J. Lee, B. Kim, and K. Lee, “Air Pollution Exposure and Cardiovascular Disease,” *Toxicol Res*, vol. 30, no. 2, p. 71, 2014, doi: 10.5487/TR.2014.30.2.071.

[65] K. Carey and T. Stefos, “Measuring inpatient and outpatient costs: A cost-function approach,” *Health Care Financ Rev*, vol. 14, no. 2, p. 115, 1992, Accessed: Jun. 20, 2024. [Online]. Available: /pmc/articles/PMC4193307/

[66] Statistisches Bundesamt, “Each hospital case cost 5,088 euros on average in 2019 - German Federal Statistical Office.” Accessed: Jun. 20, 2024. [Online]. Available: https://www.destatis.de/EN/Press/2021/04/PE21_194_231.html

[67] Eurostat, “Healthcare activities statistics - consultations - Statistics Explained.” Accessed: Jun. 20, 2024. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Healthcare_activities_statistics_-_consultations#Consultations_of_doctors

[68] S. Himmler, J. Stöckel, J. van Exel, and W. B. F. Brouwer, “The value of health—Empirical issues when estimating the monetary value of a quality-adjusted life year based on well-being data,” *Health Econ*, vol. 30, no. 8, pp. 1849–1870, Aug. 2021, doi: 10.1002/HEC.4279.

[69] L. Boiron, E. Joura, N. Largeron, B. Prager, and M. Uhart, “Estimating the cost-effectiveness profile of a universal vaccination programme with a nine-valent HPV vaccine in Austria,” *BMC Infect Dis*, vol. 16, no. 1, pp. 1–15, Apr. 2016, doi: 10.1186/S12879-016-1483-5/TABLES/7.

[70] EPA, “Mortality Risk Valuation | US EPA.” Accessed: Jun. 20, 2024. [Online]. Available: https://www.epa.gov/environmental-economics/mortality-risk-valuation

[71] M. Gustafsson *et al.*, *Quantification of population exposure to*, no. 2. 2018.

[72] B. Desaigues *et al.*, “Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY),” *Ecol Indic*, vol. 11, no. 3, pp. 902–910, 2011, doi: 10.1016/j.ecolind.2010.12.006.

[73] OECD, “Meta-analysis of Value of Statistical Life estimates - OECD.” Accessed: Jun. 20, 2024. [Online]. Available: https://www.oecd.org/env/tools-evaluation/env-value-statistical-life.htm

[74] Koh, "What is the economic value of a life year? An international comparison." Accessed: Jun. 20, 2024. [Online]. Available: https://www.dkfz.de/en/presse/pressemitteilungen/2018/dkfz-pm-18-34-What-is-the-economic-value-of-a-life-year-An-international-comparison.php

[75] Statista, "Average property insurance premiums online Germany 2019-2024 | Statista." Accessed: Jun. 21, 2024. [Online]. Available: https://www.statista.com/statistics/1122485/average-online-property-insurance-premiums-written-in-germany/

[76] Urbyo, "Maintenance costs for your condominium - Urbyo." Accessed: Jun. 20, 2024. [Online]. Available: https://urbyo.com/en/maintenance-costs

[77] D. P. Rice, "Cost of illness studies: what is good about them?," *Injury Prevention*, vol. 6, no. 3, pp. 177–179, Sep. 2000, doi: 10.1136/IP.6.3.177.

[78] C. Jo, "Cost-of-illness studies: concepts, scopes, and methods," *Clin Mol Hepatol*, vol. 20, no. 4, pp. 327–337, Dec. 2014, doi: 10.3350/CMH.2014.20.4.327.

[79] J. M. Inoriza, M. Carreras, J. M. Lisbona, E. Sánchez, and J. Coderch, "2. La despesa sanitària poblacional segons la morbiditat atesa".

[80] M. Merino, R. Villoro, Á. Hidalgo-Vega, and C. Carmona, "Social economic costs of COPD in Extremadura (Spain): an observational study," *Int J Chron Obstruct Pulmon Dis*, vol. 13, pp. 2501–2514, 2018, doi: 10.2147/COPD.S167357.

[81] J. Alvarez-Sabín *et al.*, "Economic impact of patients admitted to stroke units in Spain," *Eur J Health Econ*, vol. 18, no. 4, pp. 449–458, May 2017, doi: 10.1007/S10198-016-0799-9.

[82] J. Fernández-Ferro, C. Ordás-Bandera, J. Rejas-Gutiérrez, B. Ferro-Rey, and S. Gómez-Lus, "THE ECONOMIC BURDEN OF MIGRAINE IN SPAIN: A NATIONWIDE COST-OF-ILLNESS APPROACH FROM THE YEAR 2020 EUROPEAN HEALTH SURVEY IN SPAIN," in *ISPOR Europe 2022*, 2022. Accessed: Jun. 25, 2024. [Online]. Available: https://www.ispor.org/docs/default-source/euro2022/ispor-2022migraine-coispain-pdf.pdf?sfvrsn=87396743_0

[83] Eurostat, "Archive:People in the EU - statistics on housing conditions - Statistics Explained." Accessed: Jun. 20, 2024. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=People_in_the_EU_%E2%80%93_statistics_on_housing_conditions&oldid=266849#Housing_characteristics:_unoccupied_dwellings

[84] Renovate Europe, "Building Renovation: a kick-starter for the EU Recovery." 2020. Accessed: Jun. 21, 2024. [Online]. Available: https://www.renovate-europe.eu/wp-content/uploads/2018/09/renovation-EU_recovery-infographic2020.pdf

[85] ACEEE, "How does energy efficiency create jobs?" Accessed: Jun. 20, 2024. [Online]. Available: https://www.aceee.org/files/pdf/fact-sheet/ee-job-creation.pdf

[86] Renovate Europe, "Building Renovation: a kick-starter for the EU economy - Renovate Europe." Accessed: Jun. 20, 2024. [Online]. Available: https://www.renovate-europe.eu/2020/06/10/building-renovation-a-kick-starter-for-the-eu-economy/

[87] IEA, "Asset values – Multiple Benefits of Energy Efficiency – Analysis - IEA." Accessed: Jun. 20, 2024. [Online]. Available: https://www.iea.org/reports/multiple-benefits-of-energy-efficiency/asset-values

[88] P. Zancanella and P. Bertoldi, *Energy efficiency, the value of buildings and the payment default risk*. 2018. doi: 10.2760/267367.

[89] R. Cole -Federal Reserve Board *et al.*, “Principles for the Management of Credit Risk,” 2000, Accessed: Jun. 20, 2024. [Online]. Available: https://www.bis.org/publ/bcbs75.pdf

[90] L. Pelizzon and M. Riedel, “Creating an energy efficient mortgage for Europe: Review of the impact of energy efficiency on probability of default,” 2017. Accessed: Jun. 20, 2024. [Online]. Available: https://www.igbc.ie/wp-content/uploads/2017/10/EeMAP-Technical-Report-on-the-Impact-of-Energy-Efficiency-on-Probability-of-default.pdf

[91] J. W. Bleyl *et al.*, “Office building deep energy retrofit: life cycle cost benefit analyses using cash flow analysis and multiple benefits on project level,” *Energy Effic*, vol. 12, no. 1, pp. 261–279, Jan. 2019, doi: 10.1007/S12053-018-9707-8/TABLES/2.

[92] Comfortmeter, “Comfortmeter | Building performance.” Accessed: Jun. 20, 2024. [Online]. Available: https://www.comfortmeter.eu/en/home-eng/

[93] J. Zarnikau, “Consumer demand for ‘green power’ and energy efficiency,” *Energy Policy*, vol. 31, no. 15, pp. 1661–1672, Dec. 2003, doi: 10.1016/S0301-4215(02)00232-X.

[94] N. Nomura and M. Akai, “Willingness to pay for green electricity in Japan as estimated through contingent valuation method,” *Appl Energy*, vol. 78, no. 4, pp. 453–463, Aug. 2004, doi: 10.1016/J.APENERGY.2003.10.001.

[95] N. Zografakis, E. Sifaki, M. Pagalou, G. Nikitaki, V. Psarakis, and K. P. Tsagarakis, “Assessment of public acceptance and willingness to pay for renewable energy sources in Crete,” *Renewable and Sustainable Energy Reviews*, vol. 14, no. 3, pp. 1088–1095, Apr. 2010, doi: 10.1016/J.RSER.2009.11.009.

[96] P. Koundouri, Y. Kountouris, and K. Remoundou, “Valuing a wind farm construction: A contingent valuation study in Greece,” *Energy Policy*, vol. 37, no. 5, pp. 1939–1944, May 2009, doi: 10.1016/J.ENPOL.2009.01.036.

[97] K. Morrissey, A. Plater, and M. Dean, “The cost of electric power outages in the residential sector: A willingness to pay approach,” *Appl Energy*, vol. 212, pp. 141–150, Feb. 2018, doi: 10.1016/J.APENERGY.2017.12.007.

[98] M. Macmillan, K. Wilson, S. Baik, J. P. Carvallo, A. Dubey, and C. A. Holland, “Shedding light on the economic costs of long-duration power outages: A review of resilience assessment methods and strategies,” *Energy Res Soc Sci*, vol. 99, p. 103055, May 2023, doi: 10.1016/J.ERSS.2023.103055.

NTNU
Norwegian University of
Science and Technology

DTU
Technical University
of Denmark

BPIE

SINTEF

HOUSING
EUROPE

IREC
Shaping Energy for a Sustainable Future

ARCA NOVA
GROUP

area

INCASÒL
Institut Català
del Sòl

TNO innovation
for life

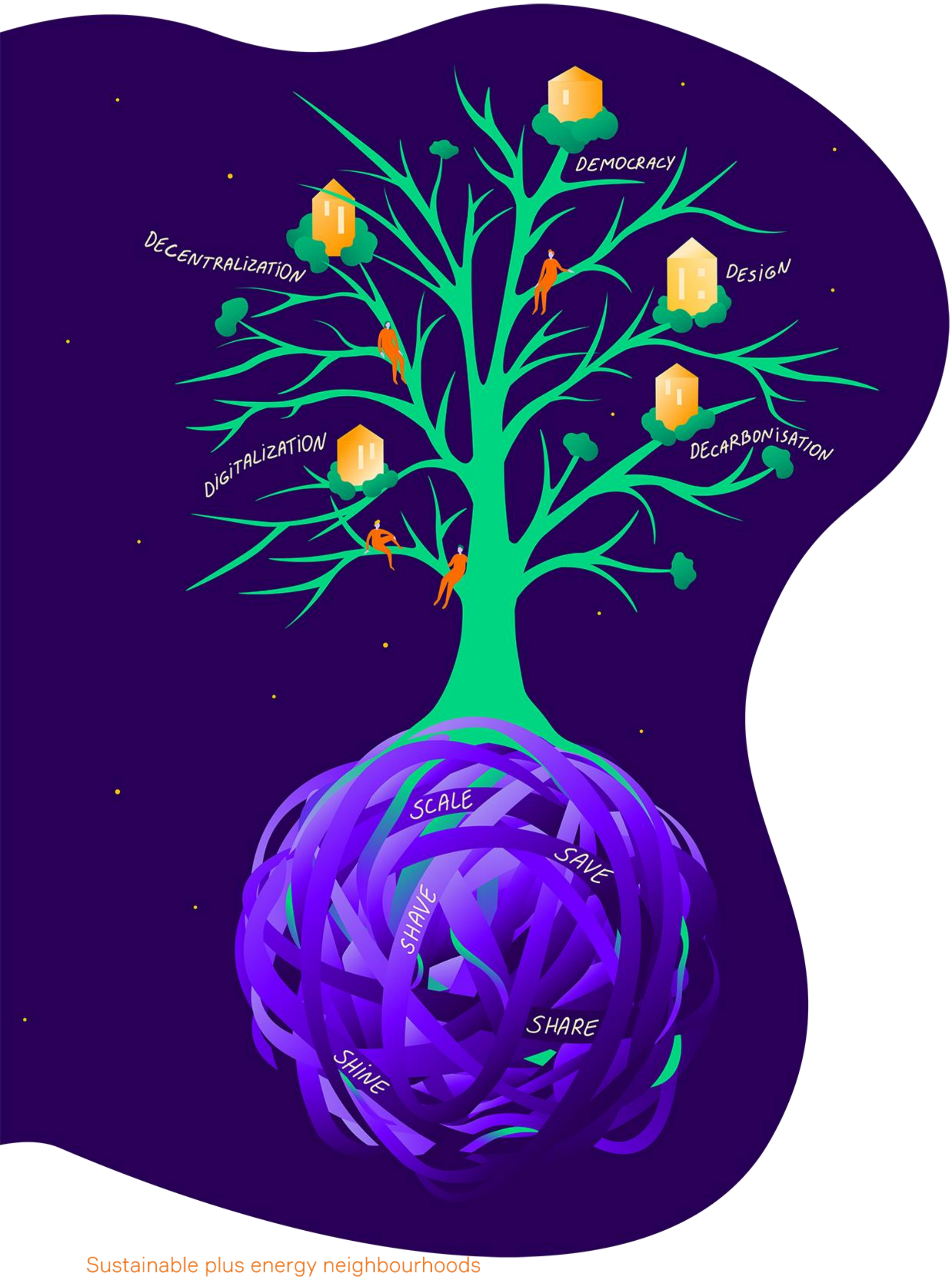
ENFOR

ABUD
Advanced Building
& Urban Design

HEIMAT
ÖSTERREICH

SIR
SALZBURGER INSTITUT FÜR
RAUMORDNUNG & WOHNEN

ECA
ENERGY
CONSULTING
AUSTRIA


DEMOCRACY
DECENTRALIZATION
DESIGN
DIGITALIZATION
DECARBONISATION
SCALE
SAVE
SHAVE
SHARE
SHINE