This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.

REFEREE: Real Value of Energy Efficiency

Multiple benefits calculation methodology

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Partners

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Introduction and summary

The REFEREE (Real ValuE oF EneRgy EfficiEncy) project aims to bring the multiple benefits of energy related measures to the attention of experts in other fields than energy. The inclusion of the multiple impacts of energy efficiency could significantly alter the result of cost-benefit evaluations (Thema, et al., 2019); substantially contributing to the economic viability of energy efficiency measures. The REFEREE project focuses on two general objectives. First, it seeks to analyse and quantify direct and indirect non-energy impacts of energy efficiency investment as well as their cost effectiveness. Second, the resulting analysis will lead to an easy-to-use tool which can support policy makers, household, business, financial institutions, and other relevant stakeholders in forming expectations as to the future impact of various energy efficiency policy scenarios. More specifically, state-of-the-art modelling techniques will be used to have a better treatment of the multiple benefits of energy efficiency technologies, which will be fed into the policy decision-support tool.

The purpose of this report is to present and align the approach of the consortium to the reporting, quantification and monetisation of the multiple benefits of energy efficiency. This deliverable is split into two parts. The first part (Part A) of the report is dedicated to the presentation of the scenario development framework and environment of the decision-support tool. It starts with a review of the link between the Future Technology Transformation models and the macroeconomic model used to estimate the impact of various policy scenarios on the indicators describing the multiple benefits of energy efficiency. Then it offers a review of key indicators that within the modelling framework can drive variation in the impact of energy efficiency policies across countries. These indicators will be reported in the form of a dashboard at the country level, to accommodate a understanding as to the key country characteristics driving variation in policy impact. Chapter 3 presents the various energy efficiency policy options that the user will be offered for the development of policy mix scenarios, which impact the tool will report. Chapter 4 briefly indicates the intention of the consortium to leverage on the national-level macroeconomic methodology to generate results that are valuable for users with different needs.

The second part (Part B) of the report presents the methodology for the quantification and monetisation of the multiple benefits of energy efficiency. The identified methods are based on state-of-the-art approaches used to model energy-efficiency and estimate the multiple benefits associated with the deployment of such measures. Multiple benefits of increased energy efficiency are presented in 5 broad macro areas: productivity, socio-economic development, health and well-being, environment and climate.

PART A REVIEW OF KEY DETERMINANTS OF VARIATION – ENERGY EFFICIENCY POLICY IMPACT ACROSS COUNTRIES

1 From FTT models to quantification of co-benefits

The modelling framework being developed in WP3 aims to link the deployment of energy efficiency policy to impacts that arise from that (the "multiple benefits" or "co-benefits"). This is done through initially soft-linking three different quantification methods (see Figure 1.1).

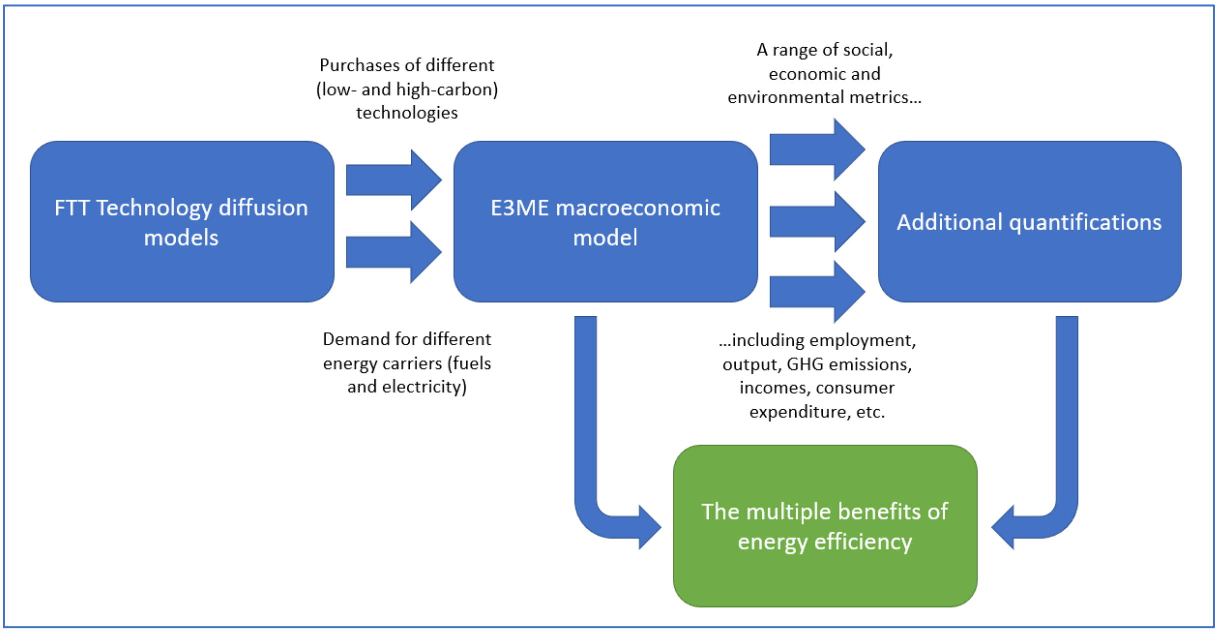


Figure 1.1 The quantification tools within Work Package 3

Across these three sets of tools, the modelling seeks to assess two specific and distinct sets of outputs from the policies that are modelled;

1. how policy affects energy demand and demand for specific technologies (within the FTT technology diffusion models)
2. how those changes in demand for different energy carriers and technologies lead to different impacts (through the application of the E3ME model and additional quantifications).

The E3ME model essentially provides a first set of metrics for the quantification of multiple benefits. As can be seen in the remainder of this report, a number of the multiple benefits to be quantified in the modelling framework rely either directly or indirectly upon impacts calculated with the E3ME model.

The E3ME model

E3ME is a global macro-econometric model, designed and maintained by Cambridge Econometrics. The model contains a country-level representation of each Member State's economic and energy systems, and is able to capture linkages between these systems. This is particularly important for understanding the wider impacts of energy efficiency policies, which affect energy demand and therefore the costs of different energy carriers, leading to economic impacts well beyond the (often marginal) changes to energy demand. For example, reducing demand for electricity can remove the need to invest in more expensive generation technologies, and therefore bring down the average retail electricity price; this reduces costs faced by industry and consumers and may lead to further positive economic feedbacks (as well as, potentially, increasing demand for electricity from the rest of the economy). The key linkages in the E3ME model are set out in Figure 1.2 below.

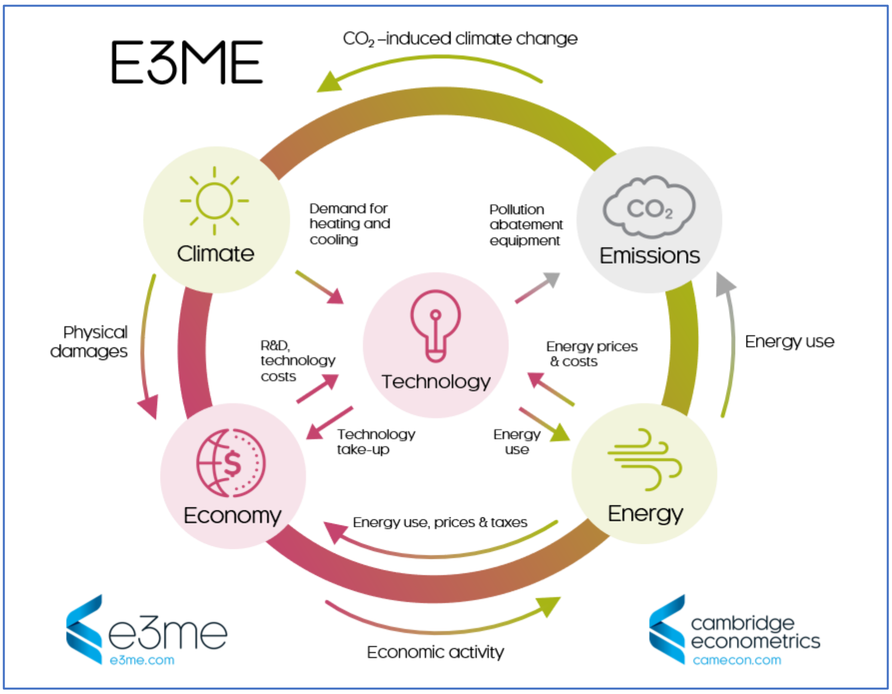


Figure 1.2 Key linkages in the E3ME model

The role of the E3ME model is therefore to ensure that the economy-wide impacts of policy are captured in the analysis. Outputs from the E3ME model are then used either as final multiple benefits indicators (such as for job/GDP creation), or used as intermediate outcomes which then feed into the calculation of multiple benefits (e.g. for health impacts, taking the emissions outcomes from E3ME and applying damage coefficients).

More detail on the E3ME model (including a full model manual) can be found on the dedicated website, http://www.e3me.com.

This initial framework, linking technology diffusion models, a macroeconomic model and additional quantifications, will initially be used for a series of full scenario runs to assess the impacts of a wide range of potential policies (in terms of scale and coverage) across the Member States. In the final tool, the E3ME model will be replaced by a series of parameterised relationships, where the parameters are directly estimated (for each indicator and Member State) on the basis of the full scenario runs that have been carried out in the E3ME model. For the purposes of shorthand, these parameterised relationships are described as 'E3ME Lite'; in practice however this will be a number of programming scripts which estimate the indicators (both final "multiple benefits" indicators and intermediate outputs which feed into the additional quantification) which in the full runs come from E3ME based on the parameters drawn from these full runs.

2 Key country characteristics driving variation in policy impact in the modelling framework

Chapter 1 shows how the modelling framework being developed will allow the evaluation of the multiple benefits associated with the introduction or modification of energy efficiency policy. The development of such tools based upon extensive historical datasets means that the modelling outcomes will be grounded in reality, reflecting the specifics of existing and historical specificities to individual Member States and their economic, energy and environmental systems.

The impacts of energy efficiency policy will vary substantially across countries, as a result of a variety of country specific factors that determine the relative impact of each measure on the range of output indicators summarised in part B.

These factors will vary from indicator to indicator, so while it is not possible to provide an exhaustive list, below we report a number of key factors that are most important in determining the relative impact of energy efficiency policies. In addition, we include indicators that can be measured within the modelling framework either as intermediate calculations or final outputs.

- Power sector generation mix
    - **Definition** – Share of each technology used in the generation of electricity (i.e Coal, oil, gas, nuclear, wind solar etc)
    - **Importance** - The current (and future) mix of power generation technologies in each country determines the impact of any energy efficiency measures which link to electrification such as in transport (battery electric vehicles) and heating (heat pumps). The generation mix determines both the relative cost of electricity, and also the level of embedded emissions from electricity generation.
- Import intensity of fossil fuels
    - **Definition** – Import share of total supply of fossil fuels (Coal, oil, gas)
    - **Importance** – Overall economic benefits from reducing fossil fuel consumption as part of energy efficiency measures is determined by how much of that fossil fuel spending was leaking out of the domestic economy through imports. While many

countries in Europe as reliant on imports to meet fossil fuel supplies and benefit from reducing their fossil dependence, there are some exceptions such as domestic coal production in Poland.

- Energy prices
  - **Definition** – Retail prices for all fuel types (fossil fuel electricity etc)
  - **Importance** – Variations in energy prices between countries has considerable implications for the relative impact of energy efficiency measures especially where fuel switching occurs. For example, there is the potential for countries with high electricity prices and low petrol prices to see worse impacts on energy poverty from fuel switching (even if that improves overall energy efficiency) than countries with lower electricity prices.
- Energy expenditure as a share of consumer expenditure
  - Definition – Total spending by consumers on all energy products as a share of total consumer expenditure. This can be split further into different energy use categories i.e. heating or transport etc
  - Importance – Determine the relative impact of reduction in energy use by consumers on household budgets
- Share of Energy demand by fuel user
  - **Definition** – Share of total energy demand used by each fuel user.
  - **Importance** – Differences in the share of energy demand for different fuel users will change the relative impact of energy efficiency policies that target a specific fuel user. For example, a country with that requires less heating and cooling (due to a temperate climate) will see proportionally smaller impacts from energy efficiency policies/measures targeting buildings or heating technologies.

3 Energy efficiency policy options

The final modelling framework will be used to allow individual users to design and model different policy scenarios. This chapter presents the list of policy options will be available to the user when designing a scenario.

The list below provides a granular review of policies available to target energy efficiency. During the development of the tool, policies will be aggregated and shown to the user grouped on the basis of expected impact.

The user will first be prompted to identify the energy carrier or technology that the policy will target. Table 1 and Table 2 present a brief overview of the energy carriers and the types of technologies available (see Appendix for a detailed review of all technologies).

Table 1. Energy carrier

Hard coal	Heavy fuel oil	Other gas	Biofuel
Other coal	Middle distillates	Heat	Hydrogen
Crude oil	Natural gas	Combustible waste	Electricity

The available technologies (e.g. combined cycle gas turbine vs solar photovoltaic in the power sector, gas boiler vs air/ground-source heatpumps in residential heating, or diesel/petrol vs electricity in road transport), and the rate at which they can spread across the population, are amongst the key determinants of the rate at which energy efficiency changes can be achieved.

Table 2. Technologies

24 individual technologies in power sector	26 individual technologies in steel
13 individual technologies in residential heating	25 individual technologies in passenger cars and trucks
n individual technologies in chemicals (under development)	

Following the choice of target energy type or technology, the user will be prompted to choose a policy that will target energy efficiency through the identified energy type/technology.

Table 3. Policy instruments

Fiscal measures	Regulations
• Taxation instruments	• Minimum Energy Efficiency
• Subsidy instruments	• Phase out of high carbon technologies
• Financial instruments	• Establishment of energy communities

After the choice of energy type or technology, the user will be presented with a list of available policy instruments and a brief description of each instrument. Upon choosing an instrument, the user will be prompted to introduce information that will determine how the policy is applied.

Once the parametrisation of the policy instrument is complete, the user will be invited to either add another policy instrument to the mix or to run the model.

3.1 Fiscal measures

The section below presents a (non-exhaustive) list of policy instruments that can be used by governments to promote energy efficiency through curbing energy consumption or incentivising the consumption/production of certain (more efficient) energy types or technologies over others.

Fiscal measures included below influence investment/consumption behaviour through changing relative costs – this involves increasing the (expected) cost of particular (typically undesirable) decisions or decreasing the (expected) cost of alternative ("desirable") decisions.

Generally, the tool user will be prompted to pick the implementation year(s) and the geographic scope of each fiscal instrument. Some instruments may require additional information.

Available fiscal measures are grouped in two broad categories; tax-based and subsidy-based instruments. A third category is also included, however it can be considered as a subset of subsidy-based instruments - financial instruments. The key difference between subsidies and financial instruments is the source of funding.

3.1.1 Taxation instruments

Energy taxation systems can encourage citizens and investors to prefer certain energy technologies over others. For instance higher energy efficiency technologies can be promoted by increasing the cost of carbon-based low efficiency technologies. Fuel excise, carbon and combustibles taxes can have positive impact in limiting the growth of low efficiency technologies resulting to growth in electrification.

The rate and the target of the tax can be critical in effectively curbing emissions and promoting higher efficiency energy technologies. Price signals below the low-end carbon benchmark of EUR 30 per tonne of CO2 often result in insufficient behavioural changes to curb climate change – often the result of Emission Trading System.

Sufficiently high carbon price floors can contribute to a move away from coal. Effective carbon tax rate on coal is in many countries close to zero. Diesel and gasoline are on average taxed above the low-end carbon benchmark. High rates are often concentrated in road-related emissions, despite non-road emissions accounting for 85% of energy-related emissions. Electricity taxes are often not differentiated by energy source, resulting to impairing on the likelihood of achieving decarbonisation through electrification – targeting combustibles through effective use of aimed fiscal tools can increase the likelihood of switching to cleaner energy sources.

Electricity excise taxes often fail to favour cleaner power sources. Most electricity taxes are not differentiated by energy source, and hence make all energy sources more expensive irrespective of the climate damage resulting from their use. Electricity taxes, as well as other levies and charges, may discourage decarbonisation through electrification.

Taxes can gradually contribute to the reduction of emissions and generate considerable revenue for the government. Revenues can improve the fiscal space of a country, allowing for fiscal reform in line with social priorities, e.g. promoting inclusive growth or research and development in climate-related issues, improve quality of public goods or mitigating adverse distributional impacts of climate change policy.

The user of the tool will be prompted to introduce information on the rate of the tax.

3.1.2 Subsidy instruments

Energy efficiency subsidies involve the use of financial and/or preferential instruments to reduce energy consumption. Unlike taxes, subsidies tend to reward certain investment practices. Instruments that can be used as subsidies are broadly grouped into four categories: direct transfers of funds, tax expenditures, under-pricing of goods/services and income/price support (Badouard & Altman, 2020).

The user will be prompted to introduce information on the total budget available for the subsidy, in order to (if required) put a hard limit on the told cost of the policy to the government.

3.1.2.1 Direct transfers

Soft loans: Governments may boost the commercial viability of projects through the provision of low interest loans or loan guarantees. Soft loan provision can allow access to finance or reduce the cost of financing.

Grants: Non-repayable fund or products distributed or offered by a public entity.

3.1.2.2 Tax expenditures

Tax reduction: The introduction of a lower rate of tax than the standard rate. Common instruments that will be considered are: reduced rate, tax rebate, tax deduction, partial exemption.

- A reduced rate is often applied on the consumption of certain goods and services, through VAT. Examples include the purchases and installations aiming at energy efficiency improvement or the consumption of certain energy carriers.
- A tax rebate or tax refund involves the return to the tax payer of a portion of the tax paid. The amount can be linked to activities related to the improvement of energy efficiency.
- A tax deduction is usually applied based on certain expenses incurred during a fiscal year. A part or the total amount of these expenses can be deducted by the taxable income, resulting in lower taxation. Such expenses are often linked with purchases and installations aimed at higher energy efficiency.
- Partial exemption involves the removal of the obligation to pay a part of a given tax, e.g. due to the installation and use of energy-saving materials and equipment.

Tax exemption: The removal of the obligation to pay a given tax.

Tax refund: A full or in part reimbursement of taxes paid.

Tax credits: The application of a reduction of the tax owed, often linked to percentage of eligible expenditures.

Tax allowance: The amount of money that taxpayer is allowed to earn without paying tax as a result of a given activity. For instance, 120% allowance permits a company to deduct an extra 20% in addition to the total eligible expenditure.

Accelerated depreciation: a change in the rate at which capital assets can be written off in company accounts. The resulting decrease in profits upon which tax is payable can increase investment incentives.

3.1.2.3 Financial instruments (low-cost access to finance)

Financial instruments are structures that allow governments to support policy aims through the provision of financial products such as loans, equity and guarantees. In contrast to subsidies, financial instruments mix public and private funding to bolster investment by reducing investment risk and offering long term orientation. The circulating nature of financial instruments safeguards the sustainability of the support provided, as the funds plus interest return to the financial organisation that issued the product and can be used for re-investment.

Products may be based on debt or equity. The exact type of the product depends on the policy target and market failure the product aims to address. Information relating to the target population and the scale of investment needed is considered during the development of the product.

3.2 Regulation

The section below presents a list of policy instruments that can be used by governments to promote energy efficiency through regulating energy consumption or investment/supply decisions.

The regulatory instruments included below influence investment/supply behaviour through the establishment of mandatory requirements/frameworks for the production of energy or energy-utilising goods.

Generally, the tool user will be prompted to pick the implementation year and the geographic scope of each regulatory instrument. Some instruments may require additional information.

The remaining of this section provides an overview of three key regulatory instruments that are commonly available to national governments and are often used to target energy efficiency.

3.2.1 Minimum Energy Efficiency

Minimum Energy Efficiency rules often involve the introduction of a regulatory specification that stipulates energy performance requirements for energy-consuming devices, buildings or vehicles. Through the use of regulatory standards, this tools curbs the maximum amount of energy that can be consumed by a device/building/vehicle for a given task.

This type of regulatory frameworks are often comprised of two parts, a set of standards and a trigger; the trigger itself is comprised of an effective date and a target population. The target population is commonly determined by the characteristics of the good; the target can be a sub-set of the total existing varieties of the good. This is particular common for MEPS focusing on energy performance of buildings or vehicles, where the renovation of buildings with poor energy performance or the removal of low efficiency vehicles is often prioritised (Sunderland & Santini, 2021).

The user of the tool will be prompted to introduce information as to the target of the Minimum Energy Efficiency rule.

3.2.2 Phase out of high carbon technologies

The phase out of high carbon technologies through regulation aims at improving energy efficiency through prohibiting the installation of technologies identified as being particularly inefficient, and/or producing large quantities of carbon. Expected direct outcomes of carbon phase out regulations include a reduction in energy consumptions (and typically also emissions).

Often the focus of the phase out is fixed on a specific economic sector. Common targets include: housing, industry, energy production and transport.

3.2.3 Energy communities

Energy communities provide organisational frameworks through various forms of legal entities (e.g. association, cooperative, partnership, non-profit, small or medium enterprise) that permit to the citizen-members of each community joint investment in energy assets (Caramizaru & Uihlein, 2020).

Energy communities can contribute to reduced energy consumption and lower energy prices through greater energy efficiency. The establishment of energy communities promotes self-consumption, greater flexibility of local services and accelerated acceptance of renewable energy types. Energy transition is further supported through the mobilisation of private capital and the reinforcing of social norms (Frieden, et al., 2021).

Despite the high potential of energy communities in terms of energy efficiency contributions, the expected impact remains not well understood at an EU level, whilst it can be expected to vary greatly across Member States. To accommodate between the need for further research and the likelihood of energy communities functioning as a key instrument in fostering higher energy efficiency in the coming years, the modelling framework will consider energy communities as a potential regulation policy by imposing an expected percentage decrease in energy consumption within a percentage of the total population. Both numerical inputs will be given by the user of the tool. The tool will then produce an estimate of the effect of the introduction of an energy community (or communities) in terms of the identified multiple benefits.

Some of the key determinants of the effective founding, functioning, and growth of energy communities are the local legislation, quality of administrative and technical infrastructure, access to information; energy market structure and electricity market maturity (Biresselioglu, et al., 2021).

4 A tool valuable for users with different needs: from national to city level

The outputs generated by the modelling framework will provide a set of indicators (with full methods set out in Part B of this report), covering the different impacts of energy efficiency policies and quantifying these across different scenarios; however, the framework is constrained (for reasons of data availability) to producing these results at the national (i.e. Member State) level.

At a national level, the policy decision-system tool (PDST) will provide an interface to create new scenarios, using the modelling framework outlined in Chapter 1, with estimation of impacts based on the modelling routines in the technology diffusion models, and multiple benefit calculation routines calibrated based on full scenario runs. Key selected impacts will be displayed in a meaningful and user-friendly way.

At the local level, the PDST will provide with impact estimates fed by key local available data. Some impacts will be scalable (for example, the impacts of a particular reduction in final energy demand can be calculated using the tool at national level, and the results assumed to hold for regions). However, any national-level estimates will not reflect the specificities of the local area (for example, examining the impact of a policy to encourage the take-up of heat pumps will have a different impact in a rural area with a large number of single family homes compared to an urban area with a large number of multi-family homes). As such, alongside the common evaluation framework giving national-level quantitative estimates, the PDST will discuss results by type of impact, from the perspective of different kinds of stakeholders, in relation to their relative contribution to overall citizens quality of life.

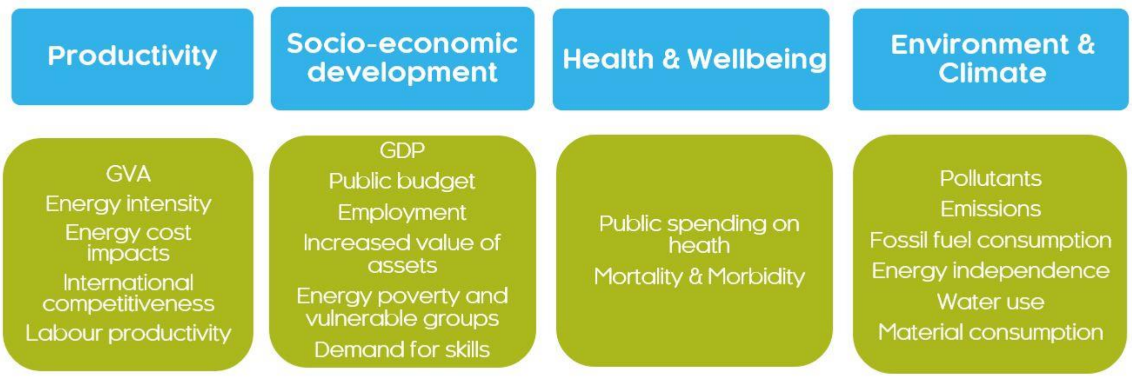
Where quantitative impacts are difficult to determine, the PDST will be able to identify key policies that drive the magnitude of benefits. It stands to reason that key policies identified with the results of the E3ME model at a national scale will also work to some extent at a more regional and/or local scale. The tool will not be able to quantitatively calculate these impacts at a local scale, but it will be able to provide a list of these key impacts and a qualitative impact assessment (high impact, medium impact, low impact...) based on specific characteristics of the local area (which will be given by the user).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No.

PART B METHODS USED TO MODEL ENERGY EFFICIENCY CO-BENEFITS

1 Review of indicators

This chapter presents the identified methods for the quantification of the multiple benefits of energy efficiency. Building on the last available scientific publications, worldwide trends, EU policy priorities and robust evidence, we have identified multiple benefits that are quantifiable within the REFEREE modelling tools. The REFEREE toolkit will analyse in-depth the co-benefits linked with four macro impact- areas: productivity, socio-economic development, environment & climate, health & well-being. **Error! Reference source not found.** shows the multiple benefits that will be quantified within the REFEREE project, althout it is important to note that this is not a comprensive list of energy efficiency benefits, as some indicators can only be assessed in qualitative terms (and will be incorporated in such



terms into the PDST).

Figure 1.1 Quantifiable multiple benefits

1.1 Productivity

Productivity measures how efficiently production inputs (i.e., labour and capital), are being used in the economy to produce a given level of output. Energy efficiency plays two explicit roles in determining productivity. First, energy is an input to production (either directly into industrial processes, or indirectly as a source of power for equipment), so reductions in energy demand (while output is still held constant) directly improve productivity. Moreover, energy efficiency measures in commercial buildings can impact the indoor environment in the building, thereby enhancing productivity of labour, i.e., achieving higher outputs with the same workforce. This is achieved through improved health and comfort for workers. In addition, efficiency improvements in commercial buildings lead to cost reduction through energy savings, increased product value through innovation, and this can lead to improved competitiveness.

Although different measures of productivity exist, this project describes productivity using four metrics, namely Gross Value Added, energy intensity, energy cost impact and international competitiveness.

1.1.1 Gross Value Added (GVA)

- **Definition:** Gross value added (GVA) is defined as the value of output minus the value of intermediate inputs, hence providing a net measure of the 'value added' at each stage of production. GVA is a measure of the contribution to GDP made by an individual producer, industry or sector.

- **Key drivers:** Energy efficiency policy impacts GVA in several ways. Energy efficiency measures applied to a particular sector will reduce the inputs required from energy sectors, increasing the value added generated for a given level of gross output. Equally the investment in energy efficiency can generate increases in output, through the installation of energy efficiency measure boosting sectors such as construction. This generates additional output and in turn additional value added.

  Methodology: Gross value added for each industry sector is calculated in E3ME by taking away the sum of intermediate production and taxes from gross output. This indicator is calculated at the Member State level, and by type of fuel user[1].

  The limitation to this calculation is that GVA is the relationship between output and intermediate consumption of products, and in E3ME it remains constant over time for most inputs from other sectors. The exception is energy sectors, where E3ME captures the impacts of energy efficiency and fuel switching on the inputs required for each sector. This means we do capture the value added generated from improved energy efficiency but miss out on any long term changes in inputs required from other sectors.

[1] Fuel users are defined as the end user categories that are consuming energy within the economy (Power generation, Industry, Residential etc). E3ME splits these fuel users into 22 final users. A full list of E3ME key classifications can be found in the Appendix.

1.1.2 Energy intensity

- **Definition:** Energy intensity is a measure of the energy efficiency which compares the value of the production with the value of the related energy consumption. The indicator identifies to what extent there is decoupling between energy consumption and economic growth.

- **Key drivers:** Energy efficiency measures leads to lower energy demand in industries, hence reducing the proportion of energy required for production. However, energy intensity is also driven by economic activity and value added in each sector, meaning that the net effect on energy intensity depends on how much value added increases compared to energy consumption.

- **Methodology:** Energy intensity is measured as the ratio between energy consumption and gross value added (GVA) in each year. The indicator is calculated based on outputs from the E3ME model;

$$Energy\ intensity = \frac{Total\ energy\ consumption\ of\ the\ sector\ (ktoe)}{Value\ added\ of\ the\ sector\ (million\ €)}$$

This indicator is calculated at the Member State level and by type of industrial fuel user.

1.1.3 Energy cost impacts

- **Definition:** Energy cost impacts is a measure of the efficiency of production, and thus competitiveness. This indicator compares the value added by the industry with the related energy cost requirements.

- **Key drivers:** Energy costs can comprise a significant proportion of the cost base for energy intensive industries. Efficiency improvements are expected to reduce energy demand for industrial production. Therefore, energy efficiency is a key opportunity for cost reduction and competitiveness improvement in industry. However, the indicator is also driven by economic activity and value added in each sector, meaning that the net effect on energy cost impact depends on how much value added increases compared to energy cost.

- **Methodology:** Energy cost impact is measured as the ratio between total energy cost and value added by industry. The indicator is calculated based on outputs from the E3ME model.

$$Energy\ cost\ impacts\ = \frac{Total\ energy\ cost\ of\ the\ sector\ (million\ €)}{Value\ added\ of\ the\ sector\ (million\ €)}$$

This indicator is calculated at the Member State level and by type of fuel users.

1.1.4 International competitiveness

- **Definition:** International competitiveness is defined as the impact of improved energy efficiency on the competitiveness of energy intensive industries in Europe. In this study, international competitiveness is defined at a sectoral level for energy intensive industries (i.e., steel, pulp & paper, aluminium, cement, glass and chemistry).

- **Key drivers:** European energy intensive industrial sectors are particularly exposed to international competition and may therefore benefit from new opportunities arising from the shift in demand towards more efficient and higher quality materials and processes. Competitiveness concerns are most evident in the sectors that are exposed to international trade, while there is a strong base in the local market. For example, if firms in these sectors have a large home market, they have more scope for benefitting from economies of scale, allowing them to charge a lower price for products that are consumed both domestically and in other countries (European Commission, 2017).

  Methodology: International competitiveness is measured as the ratio between the value added of European energy intensive industries and worldwide value added of Energy Intensive Industries. Therefore, the indicator also accounts for the impacts of energy efficiency on industries market shares, both regionally and domestically. The indicator is calculated based on outputs from E3ME model and is defined at an aggregate level for EU-27 as well as at the Member State level and by energy intensive industry.

  Measuring international competitiveness can be very challenging. The major limitation of this calculation is that the indicator is capturing changes in industries market shares. Although it does not give an accurate indication of absolute international competitiveness, changes in the market share can be a good proxy for changes in relative competitiveness given the trade relationships encapsulated in the E3ME model.

1.1.5 Labour productivity

- **Definition**: Labour productivity is defined as output per worker.

- **Key drivers:** Higher levels of labour productivity can be achieved if more capital is used in production, if capital quality increases, and if labour and capital are used together more efficiently. The E3ME model captures effects on labour productivity through the impacts of energy efficiency investments on the economy (i.e., mainly construction, manufacturing and energy sectors). These investments lead to higher employment in the targeted sectors, which ultimately delivers a higher level of gross value added. Therefore, changes in employment and gross value added may affect labour productivity, depending on how much value added increases compared to employment.

- **Methodology:** Labour productivity is calculated as gross value added (GVA) per worker. The indicator is calculated based on outputs from the E3ME model and is defined at the Member State level and by industrial sectors.

  Improved air quality and reduced outdoor pollution as a result of energy efficiency improvements in buildings can also enhance labour productivity. The limitation to the calculation as specified is that E3ME does not capture the improvements associated with reduced air pollution and improved health conditions of workers; instead, these impacts are captured through separate targeted indicators.

1.2 Socio-economic development

Energy efficiency policy is expected to have a positive impact on socio-economic development, resulting from increased economic activity, either directly or indirectly. Investments in energy efficiency contribute to boost output, while also creating additional jobs. However, these investments can potentially displace spending in other sectors of the economy, which can offset some of the positive effects on the economy. The beneficial impacts resulting from increased energy efficiency can be measured using indicators such as gross domestic product (GDP), employment, skills, public budget, value of assets, and measures of fuel poverty.

1.2.1 Gross Domestic Product (GDP)

- **Definition:** Gross domestic product (GDP) is a monetary measure of all final goods and services produced in a country in a given year. This includes metrics such as consumer spending, investments, exports and imports and government spending.

- **Key drivers:** Growth in gross domestic product (GDP) in this analysis will mainly be driven by investments in energy efficiency, reductions in imports of fossil fuels and the shift towards renewable sources of energy and changes in government expenditure.

- **Methodology:** Gross domestic product (GDP) is calculated in E3ME via the expenditure approach from the individual components of consumer spending, investment, government expenditure, imports and exports. The indicator is defined at the Member State level.

1.2.2 Employment

- **Definition:** Employment is defined as the number of net jobs that are created or lost, directly or indirectly, through energy efficiency policy. This also includes the structural shifts in employment that may occur because of the introduction of energy efficiency measures.

- **Key drivers:** Energy efficiency policy can be expected to create new employment opportunities in the sectors involved in the production of low-carbon technologies (i.e., construction, manufacturing); equally, the reduction in energy demand driven by these policies can also be expected to shrink employment in energy supply sectors. Therefore, the impact of energy efficiency policy on employment is mainly driven by the number of jobs generated from investments in energy efficiency measure, jobs created and destroyed in energy supply sectors, and indirect and induced jobs generated through supply chains and changes in aggregate wages paid across the economy.

- **Methodology:** Employment is calculated in E3ME based on long term relationships between employment and several key drivers including industry output, wages and unemployment. The indicator is calculated at the Member State level and by main industrial sectors.

  It is important to note that, although this method accounts for direct, indirect and induced employment, E3ME does not provide a breakdown of jobs that are created/destroyed at each stage.

1.2.3 Public budget

- **Definition:** Public budget is defined as the expenditure incurred by the Government in a given year.

- **Key drivers:** Energy efficiency measures applied across any sector can have an impact on the public budget, due to the cost of financing energy efficiency programmes, tax revenues from changes in economic activity, increased labour participation and consumption, and the lower cost of unemployment and social welfare programmes.

Methodology: The net impact of the policy options on the public budget is calculated in E3ME based on the impacts of each fiscal measure that is applied in the scenario, as well as the wider impacts of changes in economic and labour market activity (e.g. through taxes on products and wages). The indicator is calculated at the Member State level and by government spending categories.

1.2.4 Fuel poverty and vulnerable groups

- **Definition:** Fuel poverty is defined as the situation in which a household has access to energy but cannot afford adequate energy services to meet their basic needs. Fuel poverty can be broadly quantified as any household spending more than 10% of its annual income on energy (IEA, 2014b). According to the European Union's Survey on Income and Living Conditions (EU SILC), in 2020 8.2% of the European Union population was unable to keep their homes adequately warm (Eurostat, 2021).

- **Key drivers:** The lowest income groups spend a higher proportion of their income on energy for housing and transport. By improving energy efficiency for these groups, their demand for, and therefore spending on energy can be reduced, also allowing them to spend on other goods and services. This is dependent on any upfront costs imposed on these groups to implement the energy efficiency, and any other fiscal measures that might be put in place to support these groups.

- **Methodology:** Fuel poverty is calculated using a measure of disposable incomes after energy expenditure. This is done by subtracting consumer expenditure on energy from disposable income. Both disposable income and energy expenditures are estimated within the E3ME model. The indicator is calculated at the Member State level by income quantiles.

  The analysis will also provide the impact of the policy change on disposable income for different household archetypes – defined based on differences in the type and characteristics of their residence, such as energy efficiency band, number of bedrooms etc.

  The major limitation to this calculation is that we are not able to accurately measure the number of fuel poor households. The proposed metric will instead allow us to make narrative evaluations on the impacts of energy efficiency on fuel poverty and vulnerable groups.

1.2.5 Value of buildings

- **Definition:** This indicator is defined as the increased value of buildings in real estate markets following the implementation of energy efficiency improvements.

- **Key drivers:** Energy efficiency measures in buildings have become increasingly prominent in the real estate markets. Efficiency standards are being developed and these are considered as an important criterion for property investors, who require information about the costs and benefits associated with developing, managing and investing in buildings. Therefore, energy efficiency improvements in buildings are likely to affect the financial value attributed to properties.

- **Methodology:** Estimating the impacts for the European Union can be very challenging. This is because the value of assets is expected to vary significantly across countries and between rural and urban areas. Due to lack of data, quantifying this benefit is not feasible. However, we will review relevant literature and extrapolate results from previous studies in order to provide an approximate estimate of the impacts at EU27 level, to feed into the PDST.

1.2.6 Demand for skills

- **Definition:** This indicator is defined as the change in the demand for different skills levels within the labour market as a results of energy efficiency policy (e.g., investments in energy efficiency will boost production in the construction sector; therefore the demand for engineering/manufacturing occupations is expected to increase).

- **Key drivers:** Energy efficiency policy is expected to impact different economic sectors and have the potential to reshape significantly the European labour market. Employment in sectors implementing the policy, e.g. construction and manufacturing, is expected in increase, while after the full adoption of the energy efficiency, lower demand for energy is expected to impact negatively employment in the power sector. This will have implications for the demand for different occupations and skills.

- **Methodology:** Skills will be measured through occupations and level of qualification required. The net employment in each sector will be taken from E3ME, as explained in Section 1.2.2. The baseline and scenarios' sectoral employment will be further disaggregated into different occupations (using the nine broad occupations in the International Standard Classification of

Occupations (ISCO)). For all the EU countries and sectors, a linear trend estimation will be used to estimate the share of occupational employment in each economic sector out to 2050. Similarly, for each occupation we will use past trends of level of qualification attainted (low, medium, high) to estimate the skills level required for the implementation of energy efficiency policy. The change in demand for skills is measured as the difference between the demand for occupations and qualifications in the baseline and scenarios. Therefore, this indicator will be calculated at an aggregate level for the EU-27 as well as at the Member State level and by skill level.

The chosen method of estimation for the demand for skills delivers the most robust estimates given data availability. This type of projection of the share of occupations and qualifications in each sector should be considered as conservative. The share of high skilled workers is expected to increase in sectors where the demand for digital skills is higher, while sectors that are expected to shrink will be less attractive for high skilled workers.

The green transition is expected to change also the task content of occupations and thus the level of qualification required by the occupation compared to its task content today. A more rapid change in the skills distribution of sectoral employment could be expected when digitalisation also plays an important in this change. Additional qualitative research will be carried out to address the limitations of the approach in capturing the change in task content of occupations, and feed into the PDST in a qualitative way.

1.3 Health & well-being

Energy efficiency measures directly affect the health and well-being of both individuals and society as a whole. Improved energy efficiency leads to warmer homes, reducing the prevalence of diseases stemming from outdoor and indoor pollution. However, there are many indirect benefits from energy efficiency that should also be considered. For instance, improved health conditions may lead to savings in public healthcare spending. The potential impacts of improved energy efficiency on health and well-being can be inferred using indicators such as reduced mortality and morbidity and savings in healthcare costs.

1.3.1 Mortality & Morbidity

- **Definition:** In this study, mortality is defined as the number avoided premature deaths associated with the potential reduction in emissions and air pollutants.

- **Key drivers:** Energy efficiency improvements affect the level of outdoor air, through reduced demand for energy and therefore burning of fossil fuels. Lower levels of air pollution lead to reduced risk of respiratory and cardiovascular diseases, thereby reducing mortality rates across the affected population.
- **Methodology:** This is calculated by multiplying the potential reduction in air pollution by the number of premature deaths and quality of years lost per unit of pollutant emitted.
- The reduction in air pollution is estimated within the E3ME model, while the number of premature deaths per unit of pollutant will be derived from the literature (for example using data from the European Environment Agency on premature deaths linked to historical emissions (European Environment Agency, 2021)). This indicator is calculated at the Member State level and by pollutant types.

1.3.2 Public health spending

- **Definition:** Public health spending typically measures the final consumption of health care goods and services. In this analysis, public health spending is defined as the avoided healthcare costs associated with the introduction of energy efficiency measures.
- **Key drivers:** Energy efficiency improvements affect the level of outdoor air, through reduced demand for energy and therefore burning of fossil fuels. Lower levels of air pollution lead to reduced risk of respiratory and cardiovascular diseases, which ultimately bring savings in healthcare costs.
- **Methodology**: Public health spending is calculated by multiplying the reduction in pollutants and emissions by the estimated damage cost per unit of pollutant. Reduction in pollutants is estimated withing the E3ME model. Currently the model accounts for: carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), methane (CH_4), larger particulates (PM_{10}), volatile organic compounds (VOC), chlorofluorocarbons (CFCs), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulphur hexafluoride (SF_6). Damage costs will be retrieved from the literature (i.e., AEA Technology Environment (AEA Technology Environment, 2005)). This indicator is calculated at an aggregate level for EU-27 as well as at the Member State level and by pollutant types.

A major limitation to this calculation is that estimates of public health spending are highly dependent on the healthcare system in each country as well as on climatic factors. Our analysis does not account for differences in the healthcare system across Member States, as country-by-country damage factors are not available within the literature on a consistent basis.

1.4 Environment & climate

Energy efficiency interventions can positively affect the environment and the climate. Improved energy efficiency leads to lower energy consumption of fossil fuels and ultimately to reduced emissions, air pollution and consumption of materials. The reduction in energy consumption is also associated with reductions in water use by the power generation sector.

1.4.1 Air Pollution & Emissions

- **Definition:** This indicator is defined as the change in CO_2 emissions and air-born pollutants resulting from improved energy efficiency.

- **Key drivers:** Energy efficiency leads to changes in energy demand either through reduction in current fuel use or substitution to cleaner energy (i.e., road transport efficiency improvements from switch from petrol/diesel to electricity which lead to lower emissions intensity).

- **Methodology:** The E3ME model calculates the emissions generated from energy consumption across all fuel types and users from fuel specific emissions factors for a range of pollutants (CO2, SO2, NOx CO, CH4, PM2.5, N2O etc). This indicator is calculated at an aggregate level for EU-27 as well as at the Member State level and by pollutant types and source of emission.

1.4.2 Fossil fuel consumption

- **Definition:** This indicator is defined as the change in the consumption of fossil fuels resulting from energy efficiency policy.

- **Key drivers:** Energy efficiency measure can lead to reduction in fuel use or substitution from fossil fuels to alternative fuels (Electricity, Hydrogen, Biomass).

- **Methodology:** The E3ME model calculates fuel use for Coal Oil and gas across all fuel users either through bottom-up technology diffusion models (power generation, heating, transport and steel) or through long term relationships between economic activity and energy demand.

This indicator is calculated at an aggregate level for EU-27 as well as at the Member State level and by fuel user and by fuel type.

1.4.3 Energy independence

- **Definition:** In this study, energy independence is defined as the economic value of energy imports, expressed as a share of available energy. This indicator shows the extent to which an economy relies upon imports in order to meet its energy needs. The degree of import dependency is used as an important indicator for energy security, because in emergency situations a country may still be able to control the indigenous extraction of energy resources but might not have direct control over energy imports (Couder Johan & Verbruggen Aviel, 2017).

- **Key drivers:** Energy efficiency has a direct impact on energy demand; variation in domestic energy consumption can lead to changes in the demand for imported energy.

- **Methodology:** First, energy independence is measured as the ratio between energy consumption and gross value added in each year. The indicator is calculated based on outputs from E3ME modelling.

$$Energy\ intensity = \frac{Total\ energy\ consumption\ of\ the\ sector\ (ktoe)}{Value\ added\ of\ the\ sector\ (million\ €)}$$

Second, the Herfindahl-Hirschman Index (HHI) is used to assess the degree of concentration of import sources by country, in relation to total imports of energy products. The HHI index captures the effects of energy efficiency policy on import dependency, diversification of energy sources and geographical diversification (origins of the energy sources).

This indicator is calculated at an aggregate level for EU-27 as well as at the Member State level and by fuel type.

1.4.4 Water use

- **Definition:** This indicator is defined as the change in water use associated with potential reduction in energy consumption brought from energy efficiency measures.

- **Key drivers:** Energy efficiency measures directly impact energy demand and consumption, which ultimately affect the use of water resources in the process of energy generation.

  Methodology: Water use is calculated by multiplying the reduction in energy generation by water withdrawal coefficients. Reductions in energy generation is estimated within E3ME, whereas water withdrawal coefficients will be derived from the literature (i.e. (IEA, 2012; Larsen & Drews, 2019; Macknick et al., 2012)). This indicator is calculated at an aggregate level for EU-27 as well as at the Member State level and by energy source.

  The major limitation to this method is that water associated with energy generation tends to vary across countries, depending on the specific technologies adopted and resources availability. This method does not account for cross-country differences.

1.4.5 Material consumption

- **Definition:** Domestic material consumption measures the total amount of materials directly used by an economy.

- **Key drivers:** Energy efficiency measure and policies to incentivise its uptake are likely to impact economic activity across a number of sectors, which will ultimately affect the consumption of different materials across sectors.

- **Methodology:** Material consumption is an output of E3ME modelling. This is which estimated as a function of economic activity, material prices and two measures of innovation (investment and R&D spending). This indicator is calculated at an aggregate level for EU-27 as well as at the Member State level, by industrial sector and by type of material.

2 References

Badouard, T., & Altman, M. (2020). *Energy subsidies: energy costs, taxes and the impact of government interventions on investments: final report.* European Commission. Publications Office. doi:10.2833/546611

Bass, F. M. (1969). A New Product Growth for Model Consumer Durables. *Management Science*, 215-227.

Bass, F. M. (2004). Comments on "A New Product Growth for Model Consumer Durables". *Management Science*, 1833-1840.

Bass, F. M., Krishnan, T. V., & Jain, D. C. (1994). Why the Bass Model Fits Without Decision Variables. *Marketing Science*, 203-223.

Berger, T. (2001). Agricultural Economics. *Agent-based spatial models applied to agriculture: A simulation tool for technology diffusion, resource use changes and policy analysis.*, 245-260.

Biresselioglu, M. E., Limoncuoglu, S. A., Demir, M. H., Reichl, J., Burgstaller, K., Sciullo, A., & Ferrero, E. (2021). Legal provisions and Market Conditions for Energy Communities in Austria, Germany, Greece, Italy, Spain, and Turkey: A comparative Assessment. *Sustainability, 13*. doi:10.3390/su132212494

Caramizaru, A., & Uihlein, A. (2020). *Energy communities: an overview of energy and social innovation.* Luxembourg: Publications Office of the European Union. doi:10.2760/180576

Deffuant, G., Amblard, F., Weisbuch, G., & Faure, T. (2002). How can extremism prevail? A study based on the relative agreement interaction model. *Journal of Artificial Societies and Social Simulation*.

Fagerberg, J., & Verspagen, B. (2002). Technology-gaps, innovation-diffusion and transformation: and evolutionary interpretation. *Research policy*, 1291-1304.

Fan, Z.-P., Che, Y.-J., & Chen, Z.-Y. (2017). Product sales forecasting using online reviews and historical sales data: A method combining the Bass model and sentiment analysis. *Journal of Business Research*, 90-100.

Frieden, D., Tuerk, A., Antunes, A. R., Athanasios, V., Chronis, A., D'Herbermont, S., . . . Pastor Catalayud, E. (2021). Are we on the right track? Collective Self-Consumption and Energy Comminities in the European Union. *Sustainability, 13*. doi:10.3390/su132212494

Fruchter, G. E., & Van den Bulte, C. (2011). Why the Generalized Bass Model leads to odd optimal advertising policies. *Research in Marketing*, 218-230.

Geroski, P. A. (2000). Models of technology diffusion. *Research Policy*, 603-625.

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., . . . DeAngelis, D. L. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological Modelling*, 115-126.

Grubb, M., Kohler, J., & Anderson, D. (2002). Induced Technical Change in Energy and Environmental Modeling: Analtica Approaches and Policy Implications. *Annual Review of Energy and the Environment*, 271-308.

Hartwig, J., Kockat, J., Schade, W., & Braungardt, S. (2017). The macroeconomic effects of ambitious energy efficiency policy in Germany - Combining bottom-up energy modelling with a non-equilibrium macroeconomic model. *Energy*, 510-520.

Hourcade, J.-C., Jaccard, M., Bataille, C., & Ghersi, F. (2006). Hybrid Modeling: New Answers to Old Challenges - Introduction to the Special Issue of "The Energy Journal". *The Energy Journal*, 1-11.

Huang, W., Chen, W., & Anandarajah, G. (2017). The role of technology diffusion in a decarbonizing world to limit global warming to well below 2C: An assessment with application of Global TIMES model. *Applied Energy*, 291-301.

Jeuland, A. P. (1994). The Bass Model as a Tool to Uncover Empirical Generalizations in Diffusion of Innovation. *Empirical Generalizations Conference.* Philadelphia.

Jiang, Z., & Jain, D. C. (2012). A Generalized Northon-Bass Model for Multigenerational Diffusion. *Management Science*, 1887-1897.

Kiesling, E., Günther, M., Stummer, C., & Wakolbinger, L. (2012). Agent-based simulation of innovation diffusion: A review. *Central European Journal of Operations Research*, 183-230.

Kirman, A. P. (1992). Whom or What Does the Representative Individual Represent? *Journal of Economic Perspectives*, 117-136.

Knobloch, F., Hanssen, S., Lam, A., Pollitt, H., Salas, P., Chewpreecha, U., . . . Mercure, J.-F. (2020). Net emission reductions from electric cars and heat pumps in 59 world regions over time. *Nature Sustainability*, 437-447.

Kochenderfer, M. J., & Wheeler, T. A. (2022). Introduction. In M. J. Kochenderfer, & T. A. Wheeler, *Algorithms for Decision Making* (pp. 1-16). Cambridge: MIT Press.

Lychagin, S., Pinkse, J., Slade, M. E., & Van Reenen, J. (2016). Spillovers in Space: Does Geography Matter? *The Journal of Industrial Economics*, 295-335.

Mahajan, V., Muller, E., & Bass, F. M. (1995). Diffusion of New Products: Empirical Generalizations and Managerial Uses. *Marketing Science*, 215-227.

Mercure, J.-F. (2012). FTT:Power : A global model of the power sector with induced technological change and natural resource depletion. *Energy Policy*, 799-811.

Mercure, J.-F. (2018). Fashion, fads and the popularity of choices: Micro-foundations for diffusion consumer theory. *Structural Change and Economic Dynamics*, 194-207.

Mercure, J.-F., & Lam, A. (2015). The effectiveness of policy on consumer choices for private road passenger transport emissions reductions in six major economies. *Environmental Research Letters*.

Mercure, J.-F., Pollitt, H., Edwards, N. R., Holden, P. B., Chewpreecha, U., Salas, P., . . . Vinuales, J. E. (2018). Environmental impact assessment for climate change policy with the simulation-based integrated assessment model E3ME-FTT-GENIE. *Energy Strategy Reviews*, 195-208.

Mercure, J.-F., Pollitt, H., Vinuales, J. E., Edwards, N. R., B, H. P., Chewpreecha, U., . . . Knobloch, F. (2018). Macroeconomic impact of stranded fossil-fuel assets. *Nature Climate Change*, 588-593.

Moglia, M., Cook, S., & McGregor, J. (2017). A review of Agent-Based Modelling of technology diffusion with special reference to residential energy efficiency. *Sustainable Cities and Society*, 173-182.

Noonan, D., Hsieh, C. L., & Matisoff, D. (2013). Spatial Effects in Energy-Efficient Residential HVAC Technology Adoption. *Environment and Behavior*, 476-503.

Norton, J. A., & Bass, F. M. (1986). A Diffusion Theory Model of Adoption and Substitution for Successive Generations of High-Technology Products. *Management Science*, 1069-1086.

Orbach, Y. (2016). Parametric analysis of the Bass model. *Innovative Marketing*, 29-40.

Peterka, V. (1977). *Macrodynamics of Technological Change: Market Penetration by New Technologies.* Laxenburg: International Institute for Applied Systems Analysis.

Rahmandad, H., & Sterman, J. (2008). Heterogeneity and Network Structure in the Dynamics of Diffusion: Comparing Agent-Based and Differential Equation Models. *Management Science*, 998-1014.

Rao, U. K., & Kishore, V. V. (2010). A review of technology diffusion models with special reference to renewable energy technologies. *Renewable and Sustainable Energy Review*, 1070-1078.

Rogers, E. M. (1962). *Diffusion of Innovations* (1st ed.). New York: Free Press.

Rogers, E. M. (2003). *Diffusion of Innovations* (5th ed.). New York: Free Press.

Sharpe, S., & Lenton, T. M. (2021). Uprward-scaling tipping cascades to meet climate goals: plausible grounds for hope. *Climate Policy*, 1-13.

Sunderland, L., & Santini, M. (2021). *Next steps for MEPS: Designing minimum energy performance standards for European buildings.* Regulatory Assistance Project. Retrieved from https://www.raponline.org/knowledge-center/next-steps-for-meps-designing-minimum-energy-performance-standards-for-european-buildings/

Thema, J., Suerkemper, F., Couder, J., Mzavanadze, N., Chatterjee, S., Teubler, J., . . . Wilke, S. (2019). The Multiple Benefits of the 2030 EU Energy Efficiency Potential. *Energies*, 1-19.

Zeng, Y., Dong, P., Shi, Y., Wang, L., & Li, y. (2020). Analyzing the co-evolution of green technology diffusion and consumers' pro-environmental attitudes: An agent-based model. *Journal of Cleaner Production*, 1-11.

Zhang, T., & Nuttall, W. J. (2011). Evaluating Government's Policies on Promoting Smart Metering in Retail Electricity Markets via Agent Based Simulation. *Journal of Product Innovation Management*, 169-186.

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3 Appendix

Key E3ME classifications:

Industry Sectors	Consumer expenditure	Fuel Users	Fuel types	Material users	FTT Power technologies	FTT Transport technologies	FTT Heat Technologies	Emissions
1 Crops, animals, etc	1 Food	1 Power own use & transformation	1 Hard coal	1 Food	1 Nuclear	1 Petrol Econ	1 Oil	1 Carbon dioxide
2 Forestry & logging	2 Drink	2 O energy own use & transformation	2 Other coal etc	2 Feed	2 Oil	2 Petrol Mid	2 Oil condensing	2 Sulphur dioxide
3 Fishing	3 Tobacco	3 Hydrogen production	3 Crude oil etc	3 Forestry	3 Coal	3 Petrol Lux	3 Gas	3 Nitrogen oxides
4 Coal	4 Clothing and footwear	4 Iron and steel	4 Heavy fuel oil	4 Construction Minerals	4 Coal + CCS	4 Adv Petrol Econ	4 Gas condensing	4 Carbon monoxide
5 Oil and Gas	5 Actual rent	5 Non-ferrous metals	5 Middle distillates	5 Industrial Minerals	5 IGCC	5 Adv Petrol Mid	5 Wood stove	5 Methane
6 Other mining	6 Imputed rentals	6 Chemicals	6 Other gas	6 Ferrous Ores	6 IGCC + CCS	6 Adv Petrol Lux	6 Wood condensing	6 Particulates
7 Food, drink & tobacco	7 Maintenance and repair	7 Non-metallic minerals	7 Natural gas	7 Non-ferrous ores	7 CCGT	7 Diesel Econ	7 Coal	7 VOCs
8 Textiles & leather	8 Water and misc. services	8 Ore-extraction (non-energy)	8 Electricity	8 Water	8 CCGT + CCS	8 Diesel Mid	8 District heating	8 Radiation - air
9 Wood & wood prods	9 Electricity	9 Food, drink and tobacco	9 Heat	9 Waste	9 Solid Biomass	9 Diesel Lux	9 Electric	9 Lead - air
10 Paper & paper prods	10 Gas	10 Textiles, clothing & footwear	10 Combustible waste	10 Unallocated	10 S Biomass CCS	10 Adv Diesel Econ	10 Heatpump ground	10 CFCs
11 Printing & reproduction	11 Liquid Fuels	11 Paper and pulp	11 Biofuels		11 BIGCC	11 Adv Diesel Mid	11 Heatpump AirWater	11 N2O (GHG)
12 Coke & ref petroleum	12 Other Fuels	12 Engineering etc	12 Hydrogen		12 BIGCC + CCS	12 Adv Diesel Lux	12 Heatpump AirAir	12 HFCs (GHG)
13 Other chemicals	13 Furniture and flooring	13 Other industry			13 Biogas	13 LPG Econ	13 Solar thermal	13 PFCs (GHG)
14 Pharmaceuticals	14 Household textiles	14 Construction			14 Biogas + CCS	14 LPG Mid		14 SF6 (GHG)
15 Rubber & plastic products	15 Household appliances	15 Rail transport			15 Tidal	15 LPG Lux		
16 Non-metallic mineral prods	16 Glassware tableware	16 Road transport			16 Large Hydro	16 Hybrid Econ		
17 Basic metals	17 Tools and equipment	17 Air transport			17 Onshore	17 Hybrid Mid		
18 Fabricated metal prods	18 Household maintenance	18 Other transport services			18 Offshore	18 Hybrid Lux		
19 Computer, optical & electronic	19 Medical products	19 Households			19 Solar PV	19 Electric Econ		
20 Electrical equipment	20 Medical Services	20 Agriculture, forestry, etc			20 CSP	20 Electric Mid		
	21 Purchase of vehicles	21 Fishing			21 Geothermal	21 Electric Lux		
					22 Wave	22 motorcycles Econ		
					23 Fuel Cells	23 motorcycles Lux		
					24 CHP	24 Adv motorcycles Econ		
						25 Adv motorcycles Lux		

21 Other machinery & equipment 22 Motor vehicles 23 Other transport equipment 24 Furniture; other manufacturing 25 Repair & installation machinery 26 Electricity 27 Gas, steam & air conditioning 28 Water, treatment &supply 29 Sewerage & waste management 30 Construction 31 Wholesale/retail motor vehicles 32 Wholesale excl. motor vehicles 33 Retail excluding motor vehicles 34 Land transport, pipelines 35 Water transport 36 Air transport 37 Warehousing 38 Postal & courier activities 39 Accommodation & food services 40 Publishing activities 41 Motion picture, video, television 42 Telecommunications	22 Petrol etc. 23 Rail Transport 24 Air Transport 25 Other Transport 26 Postal services 27 Photographic equipment 28 Other recreational durables 29 Other recreational items 30 Recreational/cultural services 31 News, books, stationery 32 Package holidays 33 Education (pre & prim) 34 Catering services 35 Accommodation 36 Personal care 37 Other personal effects 38 Social protection 39 Insurance 40 Other financial services 41 Other services 42 CVM Residuals 43 Unallocated	22 Other final use 23 Non-energy use						

43 Computer programming, info services 44 Financial services 45 Insurance 46 Aux to financial services 47 Real estate 48 Imputed rents 49 Legal, account, & consulting services 50 Architectural & engineering 51 R&D 52 Advertising & market research 53 Other professional 54 Rental & leasing 55 Employment activities 56 Travel agency 57 Security & investigation, etc. 58 Public administration & defence 59 Education 60 Human health activities 61 Residential care 62 Creative, arts, recreational 63 Sports activities 64 Membership organisations 65 Repair computers & personal goods 66 Other personal services.								

67 Households as employers 68 Extraterritorial organisations 69 Unallocated 70 Hydrogen supply								