DATA-DRIVEN DECISION-SUPPORT TO INCREASE ENERGY EFFICIENCY THROUGH RENOVATION IN EUROPEAN BUILDING STOCK

D7.2 – Decision support tool scalability and replicability study

[WP7 – Practical integration in governance and local policies]

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Disclaimer

About the project

The EERAdata project will develop and test a decision-support tool to help local administrations in the collection and processing of their building and demographic data towards an assessment and prioritisation of Energy Efficiency measures in planning, renovating and constructing buildings.

While EU policy assigns a primary role to Energy Efficiency (EE), the lack of a holistic understanding of the impact of EE investments has hindered its integration in the policy-making process. Coordination between demand and supply side of energy policy is not targeted, and there is need to gather the evidence on the benefits of EE in ecological and socio-economic terms as well as on its interactions with the broader policy context and energy market.

Project's goals

The project aims to develop:

- Guidelines and roadmaps for the advancement of the clean energy transition
- Joint thematic studies and analyses reports on territorial needs and decarbonisation pathways
- A fully developed and tested decision-support tool to help local administrations in the collection and processing of their building and demographic data towards an assessment and prioritization of EE measures in planning, renovating and constructing buildings

Abstract

Deliverable 7.2 demonstrates the scalability and replicability of the decision support tool (DST). Example calculations are made for the building described in D3.4. In the example, calculations are made using the same building and renovations in three different locations in different climates. It is demonstrated that the DST it highly scalable to any city in the EU (and any location, provided the required input data can be obtained).
The modular structure of the DST allows for a flexible use and examples are given as to how the DST may be used by different stakeholders.

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List of acronyms/abbreviations

Abbreviation	Explanation
BIM	Building Information Modelling
DHW	Domestic Hot Water
DST	Decision Support Tool
EPBD	Energy Performance Buildings Directive
GWP	Global Warming Potential
IEQ	Indoor Environmental Quality
LCA	Life-Cycle Assessment
PPP	Purchasing Power Parity
PV	Photovoltaics

1 Introduction

In 2020, buildings were responsible for 36% of the global final energy demand and 37 % of the total greenhouse gas emissions. Compared to 2019, the global investments in energy efficiency in the building sector increased 11.4% in 2020 to 162 billion €. The increase was primarily due to targeted government support in Europe and is likely to decrease, as the EU member states recover from the covid-19 pandemic. If the goals set out in the Paris agreement are to be met, investment in efficiency will need to grow more than 3% annually. (United Nations Environment Programme, 2021). The EERAdata Decision Support Tool (DST) will help assess the direct cost as well direct and wider benefits of the renovation process. The methodology and end user requirements are described in Deliverable D3.4.

This Deliverable describes the limitations and scalability of the DST across building types, building locations (mainly climate zones in Europe), users and sectors and gives an outlook on possible further developments.

In order to make the DST relevant to the broader EU community and beyond, it incorporates functionalities that makes it easily scalable and replicable in countries/regions/local communities with different decision-making structures, varying access to monitoring data, diverse backgrounds of potential users, market size/renovation potential and other distinct considerations.

2 Technical scalability

The DST is built on a modular basis offering different calculation modules to the user. Each calculation module requires a number of specific input parameters and specific building information. The user is required to specify some of the parameters, but the majority of the parameters have default values and do not need input from the user in order for the tool to work. All the default values can be overwritten by the user, making the calculations increasingly specific to the actual buildings with increasing information about the buildings.

2.1 flexibility of input parameters

To aid the data import, databases have been implemented for the three frontrunner municipalities of the EERAdata project: The City of Copenhagen (COP), the Municipality of Velenje (MOV) and the Andalusian Energy Agency (AEA). Deliverable D4.4 (Databases for the EERAdata tool) provides a detailed description of the databases. The databases for the EERAdata tool comprise of the building-stock, socio-economic and life-cycle assessment (LCA) data. The building-stock data refers to general data for European buildings and specific data for the frontrunner municipalities. The socio-economic data refers to data required to assess the socio-economic impacts of energy efficiency measures in buildings and compare them against supply-side investments. LCA data refers to data which is required to assess the environmental impact of energy efficiency measures (such as refurbishment or replacement of constructional elements). These data have been categorised into different databases based on the data import requirements of the DST. The databases include minimum required data, overall desired real data, and overall desired default data necessary to run the calculation.

In order to implement new locations into the DST, the data for the new locations can be collected based on the data collection and import paradigm outlined in D4.5 (Guidelines for Data Cleaning and Preparation). The already-prepared data template can be exported and downloaded from the DST, filled in by individuals who possess “expert” access to the tool and then uploaded back into the tool ready to be used for analysis.

The renovation measures which have been applied to the buildings provided in the different regions range from U-value changes for windows to changes in the share of non-renewable district room heating. Table 1 below shows a list of data which represents some of the renovation measures applied in the DST.

Table 1 An example of the data dictionary for renovation measure data

Variables	Data Type	Description
gFactor	Double	G value for existing windows
uValueExternalWall	Double	U value for external wall
uValueWindows	Double	U value for windows
uValueBasePlate	Double	U value for base plate
uValueRoof	Double	U value for roof
windowWidth	Double	Window width
windowHeight	Double	Window height
solarShading	String	Solar shading per window

2.2 Location and building type

The modular structure of the DST allows calculations in one to five modules.
The DST will work in any location if data specific to the location is provided. Table 2 provides an overview of variables that are specific to the location.
Due to data sharing apprehensions, the DST has several implementations – one for each location/user. This gives the added benefit of having the possibility to implement the DST in the local language. Currently, the DST has been translated to Spanish. Programming wise, the only difference between the implementations are the variables listed in Table 2 and the language.

Table 2. Variables that depend on the location of the building.

Variable type	Variables	Used in
Climate data	Heating degree days in heating season	Energy demand calculation
Climate data	Lowest temperature	Heating load calculation
Climate data	Average outdoor temperature in the heating period	Heating load calculation
Climate data	Weather file including hourly values of outdoor temperature and wind speed	Indoor climate module
Climate data	Latitude and longitude	Indoor climate module
Matrix data	Primary energy factors heating	Socio-economic Module
Matrix data	Primary energy factors electricity	Socio-economic Module
Matrix data	Primary energy factors heating	Socio-economic Module
Matrix data	Social CO2 cost factors €/tCo2	Socio-economic Module
Matrix data	CO2 Tax cost factors €/Co2	Socio-economic Module
Matrix data	Income Tax Share by Country [%]	Socio-economic Module
Matrix data	Profit Rates per Company	Socio-economic Module
Matrix data	Most present Company types	Socio-economic Module
Matrix data	Relative Cost of EE Investment €/m²	Socio-economic Module
Matrix data	Renovation Job Multiplier in FTE / 1 million €	Socio-economic Module
Matrix data	Number of construction-related companies in location	Socio-economic Module
Matrix data	Labour cost per employee in construction area [€/employee*year]	Socio-economic Module
Matrix data	Unemployment rate [%]	Socio-economic Module
Matrix data	Heating cost €/kWh	Socio-economic Module
Matrix data	Electricity cost €/kWh	Socio-economic Module
Matrix data	Poverty threshold per household [€/household*year]	Socio-economic Module
Matrix data	Typical household electricity consumption [kWh/m²]	Socio-economic Module
Matrix data	Average dwelling floor area [m²]	Socio-economic Module
Matrix data	Typical household heating energy consumption [kWh/m²]	Socio-economic Module

The LCA data can be defined by the user. In the current implementation, all the default values for the LCA data are based on average values from the freely available German LCA-Database called “Oekobaudat”, provided by the German Federal Ministry of the Interior and Community. This is the case for all implementations regardless of geographic location of the building.

To demonstrate the effects of the different implementations, calculations were made in three locations on a building identical to the one used in Deliverable D3.4. In the example, the same renovation measures as in Deliverable D3.4 was used. The building conditions are summarized in table 3 and the renovation measures are summarised in Table 4. A detailed description is provided in Deliverable D3.4.

Table 3. Summary of building data in the example building.

Parameter	Value for school building in Velenje
Building use [-]	School
Window to wall ratio [-]	0.2
U values external walls [W/m^{2}K]	0.9
U values roof [W/m^{2}K]	0.7
U values base plate [W/m^{2}K]	0.3
U value windows [W/m^{2}K]	1.3
G-Value Windows [-]	0.67
Glazing windows [-]	Double glazing
Heating system [-]	District Heating non-renewable
Cooling system [-]	Not installed
Ventilation system [-]	User controlled window opening, single-sided natural ventilation
Solar shading [-]	Interior blinds
Primary Energy Factor [-]	1.8 (District Heating non-renewable)
Internal Temperature [°C]	20
Construction Material External Wall	Reinforced Concrete – Thickness: 0.2 m
Construction Material Baseplate	Reinforced Concrete – Thickness: 0.3 m
Construction Material Roof	Reinforced Concrete – Thickness: 0.15 m

Table 4. Summary of the renovation measures. The renovation measures were identical in all three locations

Measures to improve the envelope		
Type of measure	Depth	Values
Add insulation to roof	Ambitious renovation	U-Value: 0.2 W/m²K Material: XPS
Add insulation to exterior walls	Ambitious renovation	U-Value: 0.19 W/m²K Material: XPS
Exchange windows	nZEB renovation	U-Value: 0.8 W/m²K g-Value: 0.4
Add External shading devices	nZEB renovation	Blinds between panes Shading factor: 0.15
Measures to improve the building services		
Type of measure	Depth	Energy efficiency
Add ventilation and air conditioning system	Quality class 2, fan efficiency increased	q_v = 4.2 L/(s m^2 floor area), Temperature efficiency heat recovery unit = 0.75, fan efficiency = 0.7. Temperature setpoints: Heating: 20ºC, Cooling 26ºC
Upgrade heating system	Biomass (10% share of non-renewable energy to harvest biomass)	Efficiency Number: 1.52 Primary Energy Factor: 1.4
Upgrade water heating system	Biomass (10% share of non-renewable energy to harvest biomass)	Efficiency Number: 1.52 Primary Energy Factor: 1.4
Upgrade lighting system	LED + Lighting Controls for all areas	Reduce baseline demand for electrical energy 10%
Measures to improve energy supply		
Type of measure	Depth	Impact
Install solar PV	Energy self-sufficient building (nZEB)	Electricity supply 80% from onsite solar
Construct solar PV farm	Very large solar farm (10 MW)	Added solar capacity in national energy mix
Construct wind farm	Moderately sized wind farm (50 MW)	Added wind capacity in national energy mix
Replace fuel for heating	Repurpose DH system to be partially supplied by renewable waste incineration (10%)	Reduced impact of the DH system (primary energy use, GHG emission)

2.2.1 Energy demand

Currently, the energy demand module does not distinguish between building types, as this would require detailed building info and data definitions (e.g., floor plans and building zoning). For this purpose, the calculation methods would have to be extended and linked to digital 3D building models (e.g., BIM or CityGML models) in subsequent work. Nevertheless, location-specific differences such as the climatic conditions and solar radiation can be taken into account in the calculation of energy demand for space heating. The energy demand for domestic hot water is based on an average value derived from an average number of people in residential buildings.

The location-specific difference is reflected by the change in heating degree days, which adjusts according to the annual average and lowest temperature (see Table5). In the calculations for Velenje, the climatic conditions for the neighbouring city of Celje was used.

Table 5. Overview definition of climatic location-specific condition

Climatic Condition			
Parameter	Malaga	Copenhagen	Velenje
Annual average temperature [°C]	18.5	8.9	10.2
Lowest temperature of the year [°C]	2.0	-9.3	-21.1

This resulted in different energy demands for heating and domestic hot water. The final energy demand for heating increased as a result of the renovation in Malaga and in Copenhagen and decreased in Velenje. The final energy demand for DHW increased for all three locations. The results are presented in the left graph of Figure 1.

In Malaga and Copenhagen, the energy reductions due to the improved envelope were smaller than the energy increases due to a lower efficiency of the boiler. As a result, the overall final energy use increased in Malaga and Copenhagen. The opposite was true in Velenje, due to the more extreme climate in winter. The change to a biomass boiler was chosen in all three locations, because a strong reduction of emissions was achieved using almost "climate neutral" wood pellets. This can be illustrated again in the following subchapter 2.1.2 on LCA. This underlines the multidisciplinary approach of the project and the importance of multidimensional assessment.

The energy demand for DHW increased in all locations, since the "renovation measures to improve the envelope" had no effect on the reduction of the energy demand for DHW and the lower efficiency of the biomass boiler lead to an increase of the final energy demand.

The calculation of primary energy demand is based on average EU-wide primary energy factors, which therefore do not differ between the location-specific calculations in this calculation example (see Table 4). However, the DST allows a specific adjustment of the primary energy factors per calculation. The results for the primary energy demand calculation are shown in the right graph of Figure 1.

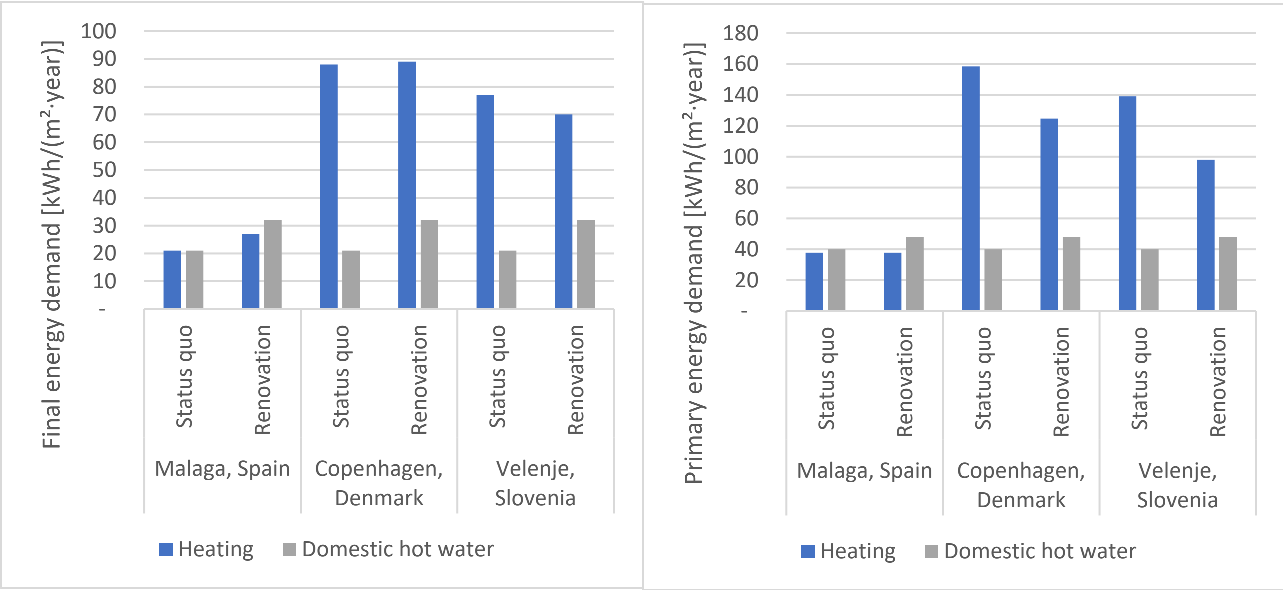

Figure 1. Summary of the energy demand calculations.

The primary energy demand decreased after the refurbishment compared to the final energy demand. This is because the primary energy factor of biomass (wood pellets) is lower than that for energy from the district heating network based on non-renewable resources.

In Malaga, the primary energy demand for space heating remained the same between status quo and renovation. In the case of Copenhagen and Velenje, the primary energy demand decreased. The primary energy demand for DHW increased in all three locations after the renovation. Because of this, and especially against the background of climate change, it is important to include the emission values in the consideration and evaluation.

2.2.2 Life Cycle Assessment (LCA)

In our LCA calculations, the operational energy demand and the embedded energy demand for the production, use and end-of-life of building materials and technical building services components is converted to global warming potential (GWP). Currently, the factors used in the calculation are based on German average values from the freely available LCA-Database called "Oekobaudat", provided by the German Federal Ministry of the Interior and Community. For our calculations they are not specific to the country or the city. The average values can be overwritten and therefore adjusted by the DST user if values specific to the site are available. In the example building the operational GWP for heating and DHW was highest in all three calculation examples before the renovation. The same applies to the embedded GWP. All results for the GWP are presented in Figure 2.

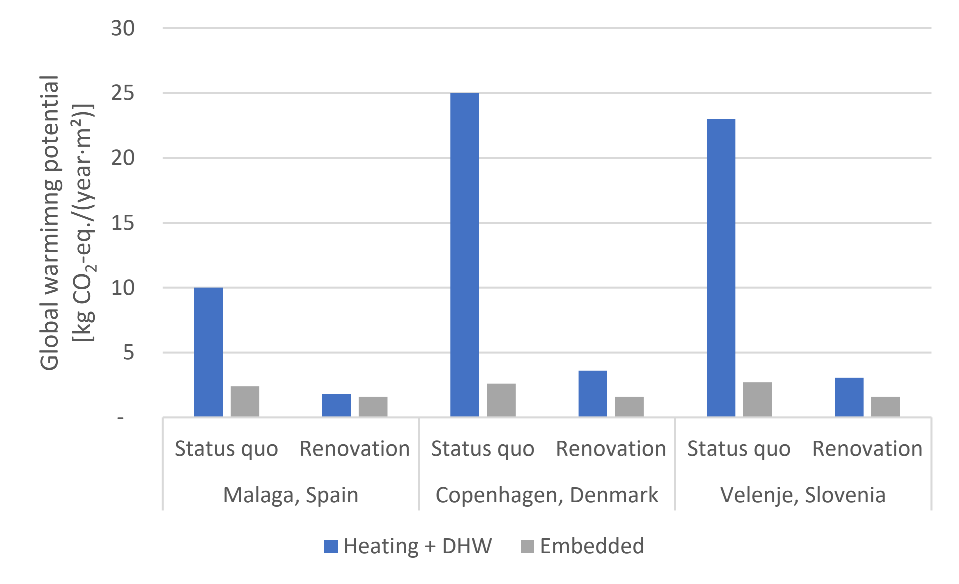

Figure 2. Overview of LCA results for Global Warming Potential (GWP)

The reduction of the operational GWP refers to the strong reduction of the emission values by changing from a district heating system with non-renewable resources to a biomass boiler (see definitions in Table 4). The wood pellets used contain wood that binds carbon from the atmosphere in the growth process. Wood pellets can therefore be considered as quasi "climate neutral". Emissions are only generated in the logging and pellet production processes, as these processes are not based purely on renewable energies. As a result, the emission values for wood pellets are significantly lower than for district heating, which in this calculation example was waste heat from processes involving the incineration of waste or fossil fuels for electricity production.

The share of embedded GWP compared to operational GWP was lower in all examples. However, the embedded and operational GWP converged strongly after renovation. The GWP that occurred from the production, use and end-of-life of the building materials and technical building components was thus much more significant and once again underlines the necessity of carrying out LCAs.

In addition, the GWP was reduced from the status quo to the status after the renovation. This was due to the fact that the existing building structure continues to be used in the course of a renovation and therefore no additional emissions were generated for the demolition of the status quo building and a replacement new building. An energetic renovation with, in the best case, the use of renewable building materials (e.g., construction wood) is therefore in any case preferable to demolition and new construction. This is also confirmed by other studies (Weiler, Harter, and Eicker, 2017). In the case of demolition and new construction, the embedded GWP after renovation would be higher than in the status quo. In addition to the emissions for demolition and new construction, there are also the emissions that occur over the life cycle of the additional insulation material.

90 - 95% of the embedded GWP that occurs over the life cycle of a building is from the building's structural elements (this is not immediately clear from the graph). The rest of the embedded GWP is accounted for by technical building services.

LCA thus extends the analysis horizon to the emission-related and climate-relevant parameter GWP and must be considered as a relevant parameter in the context of a comprehensive assessment.

2.2.3 Indoor environment

The indoor environment module is based on climate files with hourly values specific to the location. In the calculations for Velenje, a climate file for the neighbouring city of Celje was used. The differences in outdoor temperature and wind resulted in different air change rates in the reference building in the three locations. After the renovation, the mechanical ventilation system provided adequate ventilation to ensure that the CO_2 concentration was in category I (highest quality in DS/EN 16798-I 2019) all the occupied time.

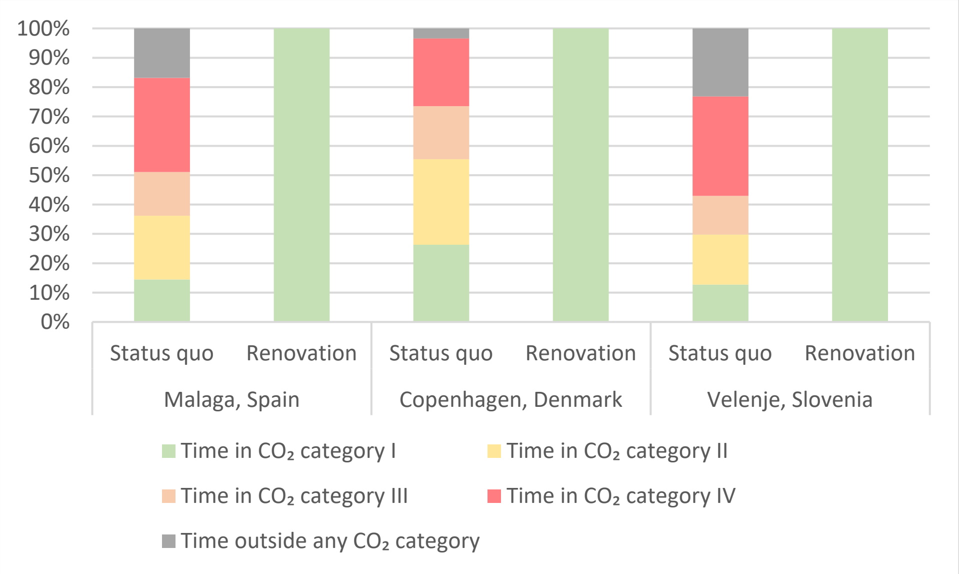

Figure 3. Percentage occupied time in CO_2 categories defined in DS/EN 16798-1 2019.

The differences in outdoor temperatures resulted in differences in indoor temperatures between the three locations. In Malaga, a large part of the occupied time had temperatures outside any temperature category. Most of these hours occurred due to too high temperatures. Even though a cooling system was installed, the set-point temperature was set to 26.0 °C. In the simulations, the cooling system was not always able to maintain a temperature of 26.0 °C. Consequently, many of the hours with active cooling ended with a temperature of 26.1 °C to 26.2 °C. Since the upper limit for Category IV is 26.0 °C, these hours were registered as outside any temperature category.

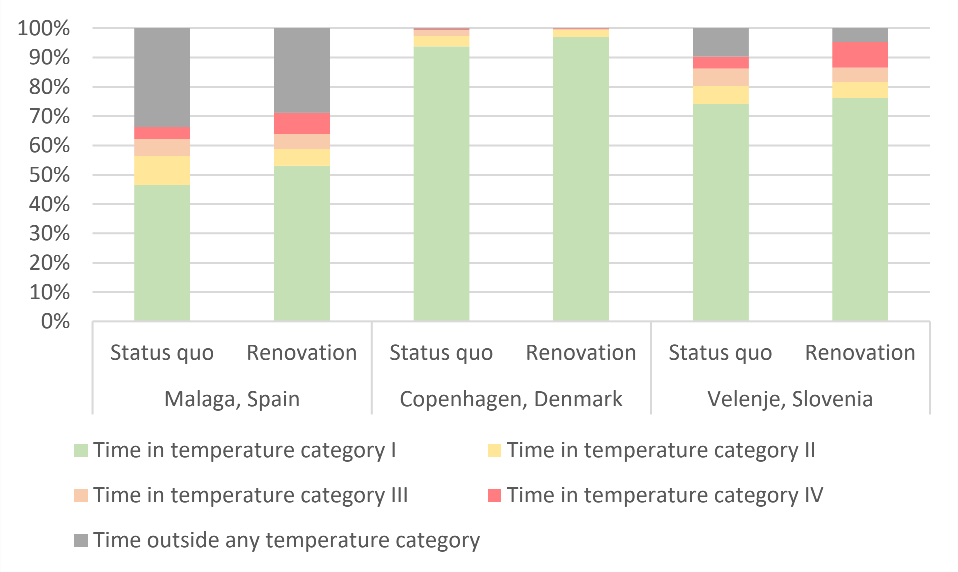

Figure 4. Percentage occupied time in temperature categories defined in DS/EN 16798-1 2019.

The improvements in indoor environmental quality resulted in higher learning among pupils and less sickness absence among pupils and teachers in all three locations. The highest increase happened in Velenje. However, after adjusting for Purchasing Power Parity (PPP), the differences in net present value between the three locations were small.

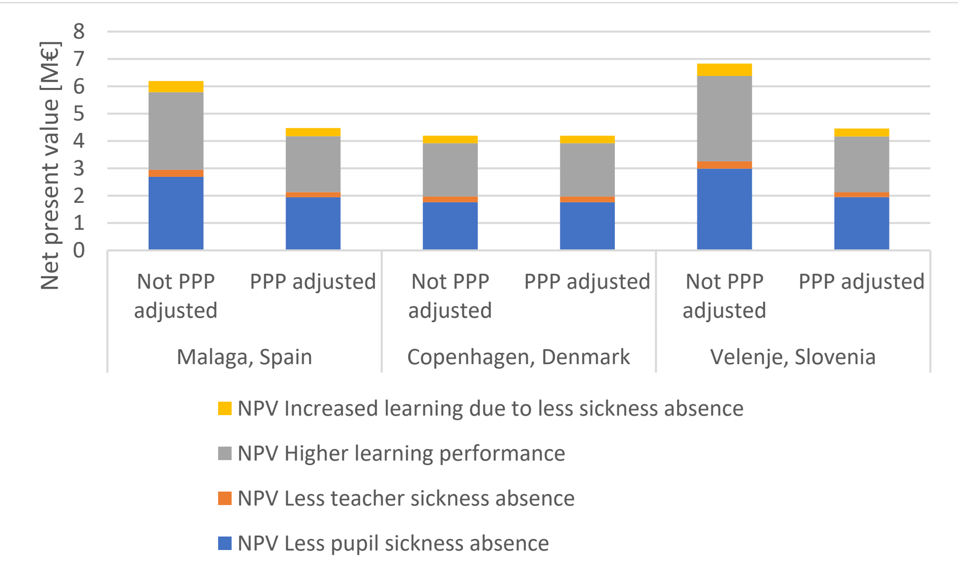

Figure 5. The Net present value of the benefits from the improved indoor environment in the three locations.

In the current implementation, the indoor climate module calculates the net present value of the indoor environmental improvements in school buildings. In other types of buildings, the indoor climate module can be used to calculate the percentage of occupied time in the different indoor environmental quality categories.

2.2.4 Socio-economic assessment

The socioeconomic module distinguishes between residential and non-residential buildings. This has multiple reasons. A main reason is that the sub-module fuel poverty in households only produces results for residential buildings. Other factors which are affected are the electricity and heating energy costs, which are cheaper in non-residential buildings. Also, the cost estimate for the renovation distinguishes between residential and non-residential projects. The composition of energy sources, especially heating differs significantly between residential and other buildings. This is reflected in the model.

The increased air combined with a lower efficiency of the boiler resulted in an increase in the combined energy use for heating and DHW in all three locations. This influenced the heat cost savings, which were negative indicating that the cost of heating increased as a result of the renovation.

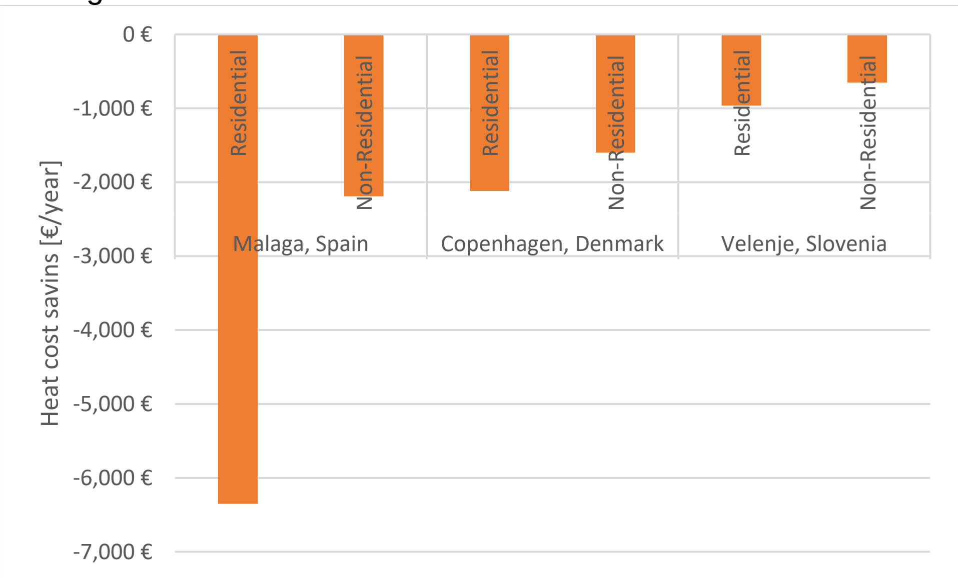

Figure 6. Heat cost saving due to the renovation. A negative saving means that the expense increased as a result of the renovation.

The calculations of the CO_2 emissions do not distinguish between building types. The differences in CO_2 emission reductions between the three locations resulted in different cost savings between the cities (Figure 07).

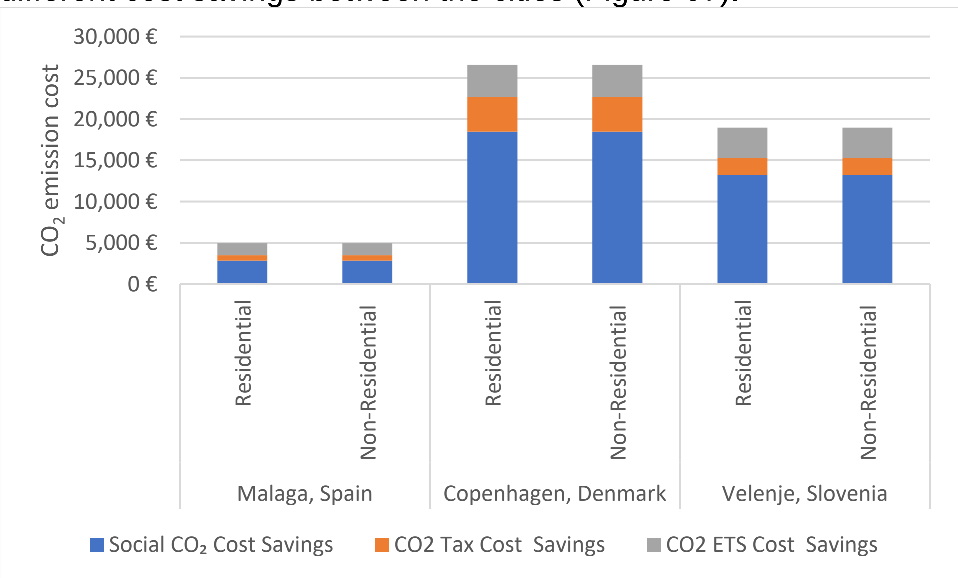

Figure 7. Cost of CO_2 emissions in the three locations.

The modelled renovation created different amounts of jobs in the three locations which led to reduced unemployment spending (Figure 08).

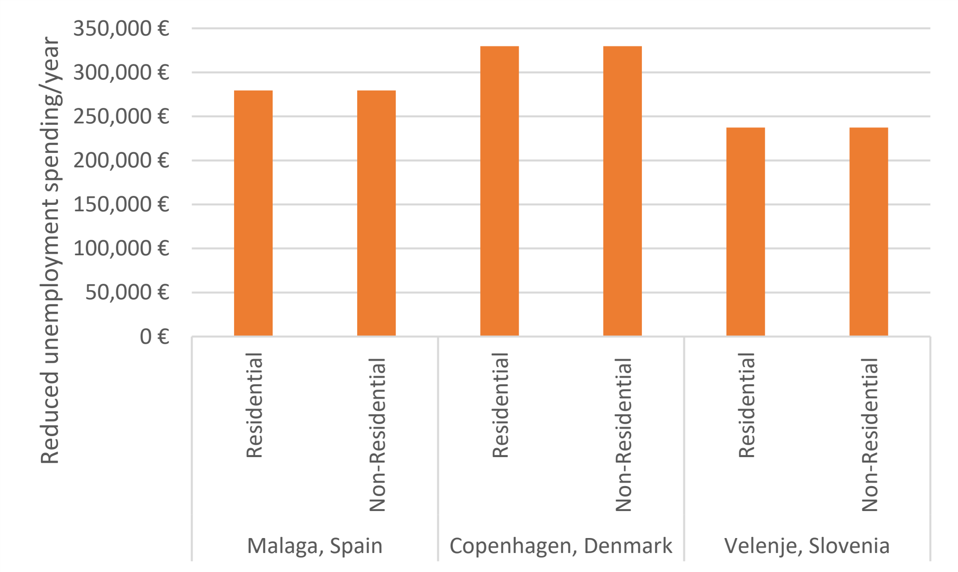

Figure 8. Reductions in unemployment spendings due to the renovation.

The renovation gave the highest tax returns in Copenhagen but only a small portion of it was tax returns to the public budget (Figure 09). In the current implementation of the DST, the model of tax is based on German tax legislation. Models of tax legislation for other locations can be added in an updated version of the DST.

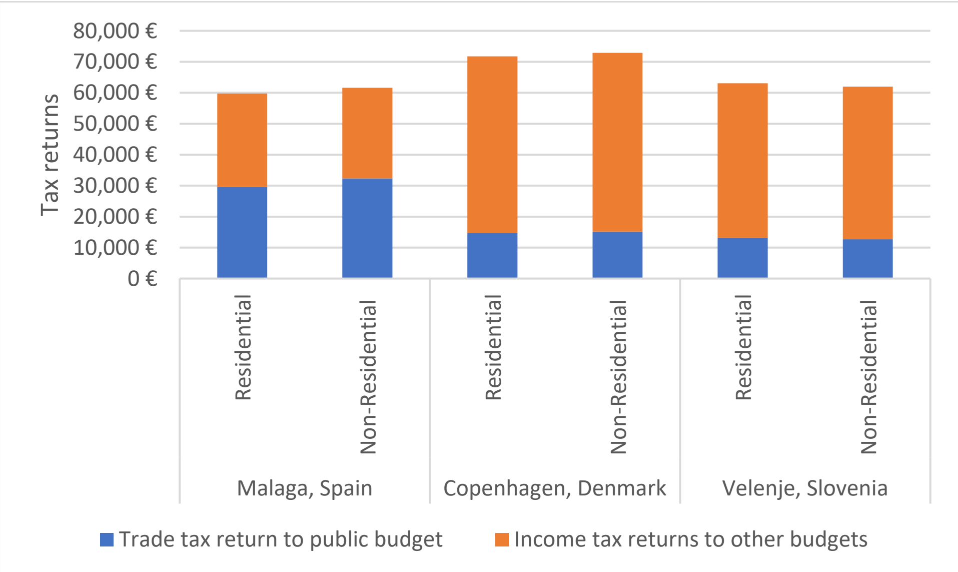

Figure 9. Taxes returned to the public as a result of the renovation.

2.2.5 Supply-side assessment

The Supply side assessment module uses the heat demand from the energy demand module to calculate the primary energy demand based on fuel composition on each location. Grid losses are included if the heat is supplied by district heating. The heat was supplied by district heating in Copenhagen and Velenje and by gas in Malaga. Figure 10 shows the results of the calculations in the three locations. In Copenhagen and Velenje grid losses and differences in fuel composition supplying the district heating grid resulted in differences in energy demands. Both the energy demand and the primary energy demand for heating increase after the renovation in

Malaga. In Copenhagen, the heating demand increased marginally, while the energy demand decreased in Velenje.

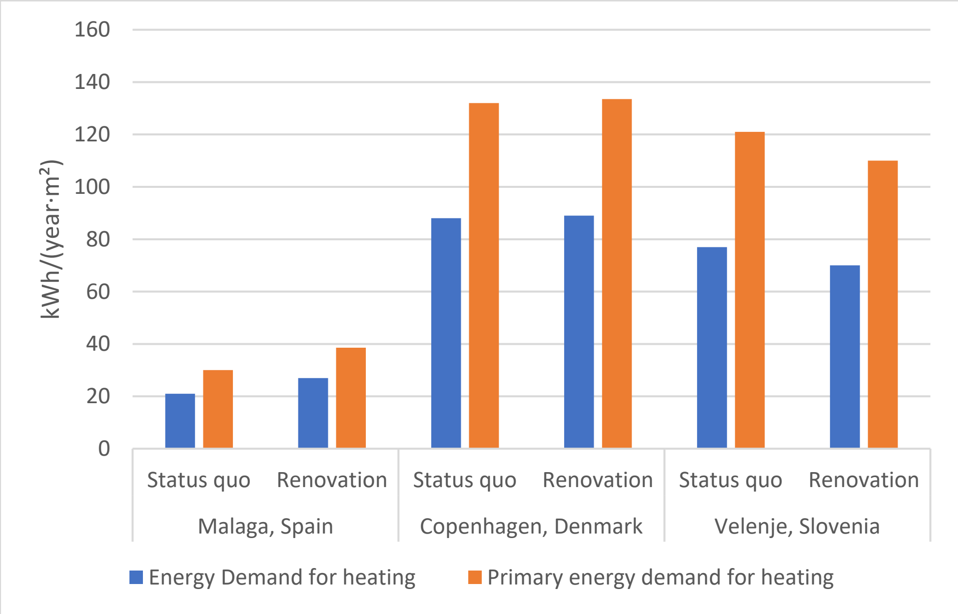

Figure 10. Total and primary energy demand from the energy supply side module.

The DST provides data for electricity production for all EU28 countries individually. In the supply side assessment module, this data was used to convert electricity demand to primary energy.

A part of the renovation was to add PVs to the building to cover a part of the electricity demand. Figure 11 shows how the electricity demand was covered before and after the renovation. Due to the mix of fuels and renewables in the electricity production, the primary energy demand was highest in Velenje even though the electricity demand was highest in Copenhagen. The PV installation did not result in a decrease in the electricity use. But the primary energy demand was reduced in all three locations due to the low primary energy factors for PV.

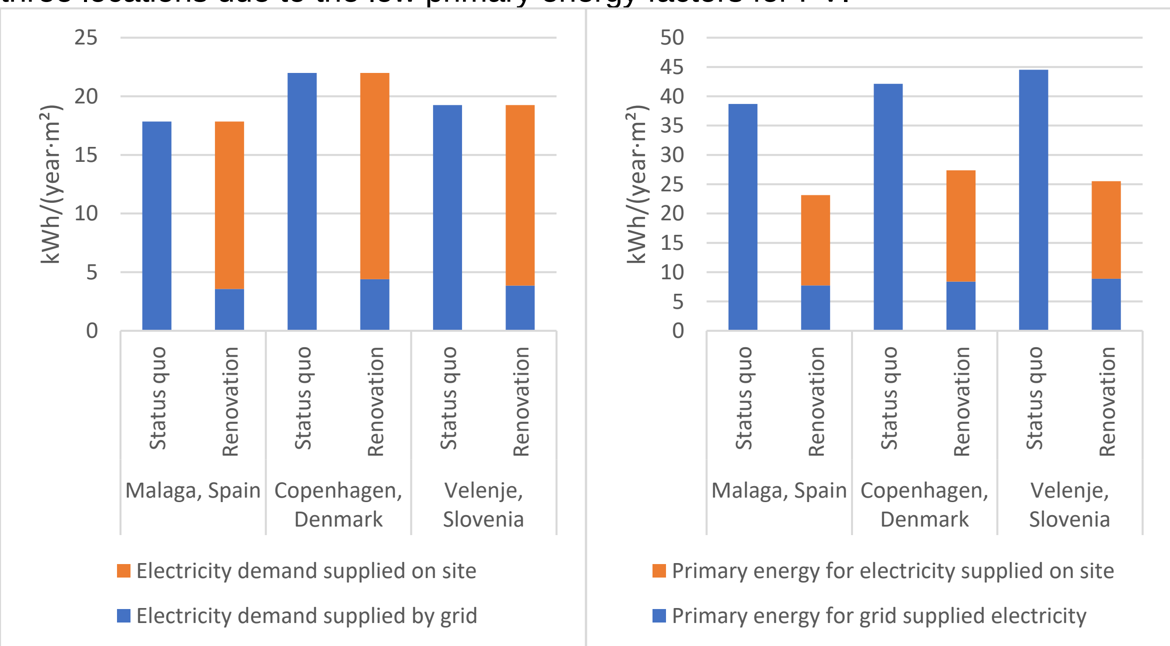

Figure 11. Electricity demand and supply (left) and primary energy demand and supply for electricity (right).

3 Stakeholder flexibility

The modular structure of the DST provides a high degree of flexibility and scalability in relation to different stakeholders. A consultant may use the DST as an aide in design of a specific renovation case. A large building owner can use the DST to assess which buildings to renovate first. A municipality may use the DST to develop business cases quantifying the energy benefits as well as the non-energy benefits to inform the politicians and decision makers. In a political context, the tool may be used to provide cost estimates of specific carbon emission reduction targets and thereby help to find a path to the cost-optimal solutions.

3.1 The DST as a design tool

In this case, the DST will provide insights on the consequences of design decisions on a specific building. The workflow could be to test different renovation measures to gain an understanding of the underlying structures and consequences of the measures. In this case, the energy demand module will provide an overall estimate of the energy demand. In a design situation, this could be compared to results of tools typically used during design. The LCA module would be used to give an overview of embodied carbon and global warming potential under different renovation measures. The indoor climate module could be used to provide estimates of the indoor environmental quality (IEQ) and in schools, the module could also be used to quantify the financial consequences of IEQ improvements on learning and sick leave. The socioeconomic module could be used to inform the consultant of the socioeconomic consequences of different renovation measures.

3.2 Large building owner

An owner or an administrator of a large building stock can use the DST to assess which buildings to renovate first. In this case, the workflow would be to enter data for the entire building stock and then run the DST in batch mode, going through all the buildings one at a time. Running different renovation measures on all the buildings will give an overview of the renovation potential and the financial consequences of renovations under the different levels of ambition.

3.3 Municipality

In a municipality, the DST can be used to provide insights into the renovation potential of the building stock under administration. After importing data on the buildings under administration, the outputs from the DST can be used to develop business cases quantifying the energy benefits as well as the non-energy benefits to inform the politicians and decision makers. The DST can be used on all buildings to create an overview of the potential for renovation. Examining specific buildings, the quantification of the non-energy benefits can be used to generate business cases involving both energy and non-energy benefits of renovation measures.

3.4 Other stakeholders

In a political context, the tool may be used to provide cost estimates of specific carbon emission reduction targets. This can be done by use of the output from the energy demand, the LCA and the supply side modules to quantify reductions in carbon emissions under different renovation measures and supply side investments. In this way, scenarios can be established that all meet the reduction targets. The results from the indoor climate and the socioeconomic module can be used to assess the financial and societal consequences of the different scenarios.

Utility companies in collaboration with municipalities can use the indoor climate module to learn about the consequences of proving flexibility to the grid (electricity and/or district heating) by controlling the indoor temperature based on conditions of the grid.

In a larger context, the agencies under the EU member states may use the DST to learn about the socioeconomic consequences of legislation and building codes.

4 Outlook

The flexibility and modular structure of the DST allows for future developments in various directions.

Currently, the Indoor climate module is based on school buildings and upgrades including calculations for residential buildings and office buildings are foreseen. In residential buildings, there are indoor environmental effects on the residents' health and well-being. The indoor climate module could be further developed to quantify the potential health benefits of an improved indoor residential environment as a result of a renovation. The increased risks of asthma, allergic rhinitis and chronic bronchitis attributable to mould and dampness could be modelled as a function of mould exposures, calculated by the indoor climate module. Similarly, effects from particulate matter on chronic bronchitis and health-care visits due to asthma, respiratory and cardiovascular diseases could be modelled and quantified. Each of these health outcomes could be economically valuated as a cost of illness or a willingness to pay.

In office buildings, the indoor environment has an effect on the employees' cognitive performance. Effects on both temperature and CO_2 concentration could be modelled to quantify the improvement or reduction in office worker performance and the subsequent production gain/loss.

In the current implementation, the DST takes the effects of temperature and CO_2 concentration into account. In future developments, the DST could be expanded to also include effects of other indoor environment such as light and noise.

The newly issued draft revised EPBD requires member states to elaborate national building renovation plans that rely on evidence-based estimates of expected energy savings and wider benefits (EPBD 2021). The EERAdata Decision Support Tool addresses exactly these elements and can, with additional development and verification, support member states in elaborating such plans.

5 Conclusion

With a few exceptions, all modules in the DST are scalable across all large cities in the EU and across many countries in the world. The DST can provide insights into energy demand, LCA, indoor climate, socio economics and assessment of supply side in most building types. Currently, the DST can quantify financial non-energy benefits for improved indoor environments in schools. With a few extensions, the applied methodology can be used to evaluate the wider benefits of renovating office- and residential buildings.

The DST may help the EU member states to address the requirements in the newly issued draft revied EPBD to formulate national building renovation plans, based on expected energy savings and wider benefits.

6 References

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