World Conference on Timber Engineering
Oslo 2023

WEB-GIS-TOOL: ESTIMATION OF GREENHOUSE GAS SAVINGS DUE TIMBER USE IN THE URBAN BUILT ENVIRONMENT

Caya Zernicke[1], Annette Hafner[1], Andreas Abecker [2], Harro Stolpe [3]

ABSTRACT: The development of German cities, municipalities and urban areas requires a high amount of material and energy. Responding to this requires a commitment to achieving national climate change targets, as they have different options for sustainable development. Especially urban planning can create linkages for climate protection measures through its interdisciplinary field of activity. Further, urban planning has an impact by directly affecting the construction and housing sector, one of the major emitters of greenhouse gas emissions. To support decision-making processes or measures for climate protection in urban areas, the web-GIS system Holzbau-GIS has been developed. This GIS-based web-tool calculates the GHG reduction potentials and temporal carbon storage for new construction and refurbishment with wood. This paper summarizes the method to calculate these potential GHG reductions due to timber use in the urban built environment. Through the intersection of spatial geodata and recent building-specific research data, various conclusions can be drawn within the web-GIS system regarding basic data, new construction, and refurbishment with wood. The paper also shows illustrative examples and their visualization in the web-GIS system. It became apparent that the Holzbau-GIS could serve as part of the digital transformation of municipalities and emphasize the contribution of timber buildings.

KEYWORDS: geographic information system GIS, timber construction, temporal carbon storage, climate protection

1 INTRODUCTION

1.1 GENERAL

Municipal self-governance is one of the essential principles of the political structure of the Federal Republic of Germany. In the increasing variety of multidisciplinary activities, municipal self-government plays a key role today more than ever before. Issues of municipal policy include, especially recently, the protection of the environment and natural resources, budgeting, and privatization. Here, the different spatial, socio-political, structural and geographical conditions will be considered specifically. [1] Consequently, cities, municipalities and urban areas must contribute to achieve the national climate protection targets, as they have various directing options toward a sustainable development. By acting responsibly, they can have a direct impact on regional urban development, especially with the focus on climate mitigation and climate adaptation. The building sector can be a key element of municipal climate protection since buildings usually have a central impact on urban development. They significantly shape the structure of the city by defining its use in terms of working, housing and infrastructure. [2-8]

In the past, the German construction industry has focused primarily on energy efficiency to meet climate protection targets. Now, the focus is shifting increasingly towards the material choice for new construction or refurbishment and, in terms of urban planning, wood as a building material is gaining in significance since. [4] In the future, the use of sustainable renewable materials will play a significant role in this context. [7, 9, 10] Therefore, the carbon footprint of building materials and the additional reduction potentials using life cycle assessments (LCA) move further into the spotlight. The emissions of building materials in production, processing and deconstruction must be considered in terms of their environmental impact, but also regarding the consumption of raw materials, flexibility, service life and recyclability, for instance. [2, 11]

1.2 MOTIVATION AND SIGNIFICANCE

Not just since Glasgow 2021, fundamental changes are needed to meet the 1.5°C target. In order to limit the temperature increase to this level, great efforts are required, especially at the regional level. Municipalities have to play a significant role in the implementation of these targets. Thus, the perspective must be directed towards the mechanisms and possibilities of urban planning. Especially urban planning can create possible

[1] Caya Zernicke, Ruhr-University Bochum (RUB), Germany, Resource efficient Building, caya.zernicke@rub.de;
[1] Annette Hafner, Ruhr-University Bochum (RUB), Germany, Resource efficient Building, annette.hafner@rub.de
[2] Andreas Abecker, Disy Informationssysteme GmbH (disy), Germany, andreas.abecker@disy.net
[3] Harro Stolpe, Ruhr-University Bochum (RUB), Germany, Environmental Engineering+Ecology, harro.stolpe@rub.de

https://doi.org/10.52202/069179-0521

linkages for climate protection measures through its interdisciplinary field of activity. [2-7]

Digital solutions are gaining importance and supporting innovative decision-making. For this purpose, digital solutions are increasingly being developed and offered to cities for sustainable development. Geographic information systems (GIS), for example, has been a common tool even in urban planning for many years. A GIS, in general, is a computer-based system, which processes geospatial data. This system consists of hardware, software, data, applications, and services (HSDA model). With these four components, geospatial data can be digitally captured, stored, managed, updated, analysed, and presented alphanumerically and graphically. Thus, complex issues can be presented in a structured way. Especially for urban development, GIS systems have become indispensable tools for planning and decision making. By linking spatial or locational data, solutions can be crystallized more quickly and effectively from GIS-based decision-making templates. [12-18]

In general, urban environmental protection including the construction of timber buildings is partially combined with the development of intelligent software solutions. The measures shown in the web-tool Holzbau-GIS certainly have the potential to contribute to environmental relief. However, the right parameters and framework conditions for realising these potentials must be established. [13]

2 PROJECT DESCRIPTION

The R&D project Holzbau-GIS (Timber Construction - GIS) provides information on potential greenhouse gas (GHG) reduction due to timber construction and contextualizes the results of the GHG calculation on a municipality-wide consideration. It is focusing on possible climate protection measures through buildings including potentials using renewable building materials. By intersecting spatial geodata and building-specific research data, various conclusions can be drawn within the web-tool regarding basic data, new construction, and refurbishment with wood. Different scenarios project feasible reduction potentials for new timber buildings or refurbishment measures on existing buildings.

2.1 SOFTWARE ARCHITECTURE

An interdisciplinary team (architects, software developers, environmental engineers) developed the web-GIS system Holzbau-GIS and piloted it in close collaboration with the sample municipality of Menden (Sauerland) in Germany. The project combined contributions from four operating areas:

- Geodata-Management (lead partner: eE+E)
- GHG-Calculation (lead partner: ReB)
- Scenario-Management (lead partner: ReB)
- Web-GIS system (lead partner: disy)

The Geodata-Management classifies the building level based on available geodata. Various available municipal geodata like building footprints, 3D building models, historical satellite images, etc. are utilised to set up basic data to provide a sound starting point for the GHG-Calculation by the research partner Environmental Engineering+Ecology (eE+E).

The GHG-Calculation defines the GHG reduction potential by replacing mineral constructions with timber constructions. In order to quantify this potential, established methods for the LCA of buildings according to DIN EN 15978 [19] and research data [9, 20-22] are utilised for new construction scenarios. For a more detailed description, see Chapter 3.1. For refurbishment, the calculation of potential reductions due to the material choice, it is necessary to introduce a new methodology for LCA of refurbishment measures, which can be found in [23, 24] and summarized in Chapter 3.2. Based on this, the research partner Resource efficient Buildings (ReB) calculates the GHG reduction potentials.

The Scenario-Management defines the total amount of GHG reductions, extrapolated to the study area of the test municipality of Menden (Sauerland). It is the first time of connecting geospatial data of a whole municipality with the results of recent developed methods of LCA for refurbishment and valid LCA data for new constructed buildings. Both, the geodata management and the development of the method for calculating the GHG reduction potentials enable the derivation of various scenarios for new constructions or refurbishment measurements.

Referring to the web-GIS system, the research partner Disy Informationssysteme GmbH provides the Holzbau-GIS tool, based on its business intelligence and geodata analytics platform disy Cadenza [25] Figure 1 shows main technical aspects of the client-server based web-GIS system. The data is stored in a PostgreSQL DBMS with the PostGIS extension for managing spatial data. The database is managed by the disy Cadenza platform, which provides services such as user, roles and rights management, logging functionalities, as well as interactive data access, visualizations, and analytics.

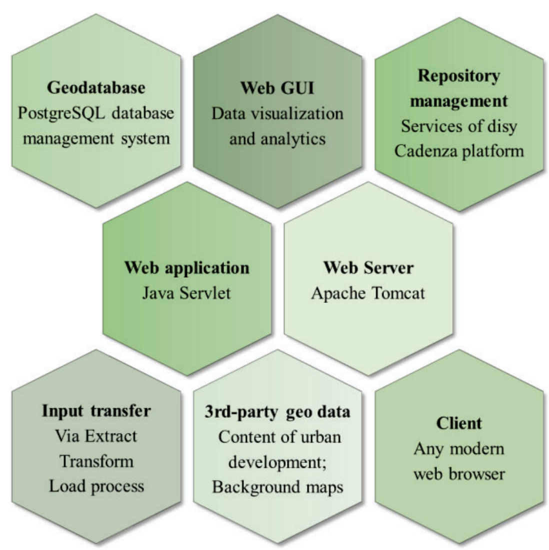

Figure 1. *The different components of the web-GIS system (random order)*

https://doi.org/10.52202/069179-0521

2.2 SOFTWARE FUNTIONALITY

Holzbau-GIS is an interactive web-based tool, which offers the option of selecting individual topics via the main menu. The display levels range from a very global overview down to the individual building. The data visualizations can be adapted or filtered according to the user's needs. The currently version provides basic functions, new construction scenario and refurbishment scenario. The data can be presented as interactive tables and charts or in a map view. Multidimensional data can also be aggregated on different spatial and temporal scales.

3 METHOD DESCRIPTION

In addition to the general data on the existing building stock, the web-GIS system contains further data on urban land use planning and environmental planning, among other things. This is followed by the results of the calculation scenarios.

This next section describes the procedures and methods utilised in these scenarios, while the main elements of the methodologies are presented in the following subsections 3.1 refers to the new construction scenario, while 3.2 describes the refurbishment scenario.

3.1 NEW CONSTRUCTION

Referring to Figure 2, the method of the new construction scenario starts with a compiled LCA data basis on new buildings. Therefore, data of former research projects "THG-Holzbau" [9, 21] for residential buildings and "HolzImBauDat" [20, 22] for non-residential buildings are operating as the general data basis for this scenario. In both projects, LCAs were conducted for the timber buildings and their functionally equivalent mineral buildings. By using this data, it is possible to obtain holistic statements on residential and non-residential buildings, shown here in Figure 2 in "building use". Further differentiations are also applied within the "building type", subdividing residential buildings into single-family and multi-family houses. For non-residential buildings, the new construction scenario provides conclusions for these different building types: agricultural or non-agricultural buildings, office and administrative buildings or other non-residential buildings.

These different "LCA results" were elaborated for each building type of new construction scenario: (1) GHG emissions of new buildings constructed with timber or as mineral buildings (2) GHG reduction potential by replacing mineral structures with wooden structures and (3) temporary carbon storage of the implemented renewable building materials. The outcomes of GHG emissions, GHG reduction potential, and temporary carbon storage refer to the gross external area (GEA) and thus the resulting units are given in kg CO2 Eq. /m² GEA.

The final phase of this methodology for new constructions includes the linkage of the LCA results (building-scale) to the "municipal level". Since new buildings are maximally planned without being built yet, those urban land use planning of the municipality can serve as the linking element, in detail, data of the urban land use planning is utilised to establish this connection.

Within the urban land use planning process, new construction areas are elaborated, ultimately permitted, and publicized in development plans. Using parameters which must be defined within this planning process and published as part of the development plans, we can calculate the maximum permitted GEA of the new construction areas. This output is given in m² GEA, which allows us to extrapolate the LCA results related to future construction activities of the municipality.

Summarized, this section described the methods of the new construction scenario including the differentiation of building types and LCA results. By combining given parameters of development plans and LCA results, quantitative data can be provided for GHG emissions, GHG reduction potential and temporary carbon storage for new construction.

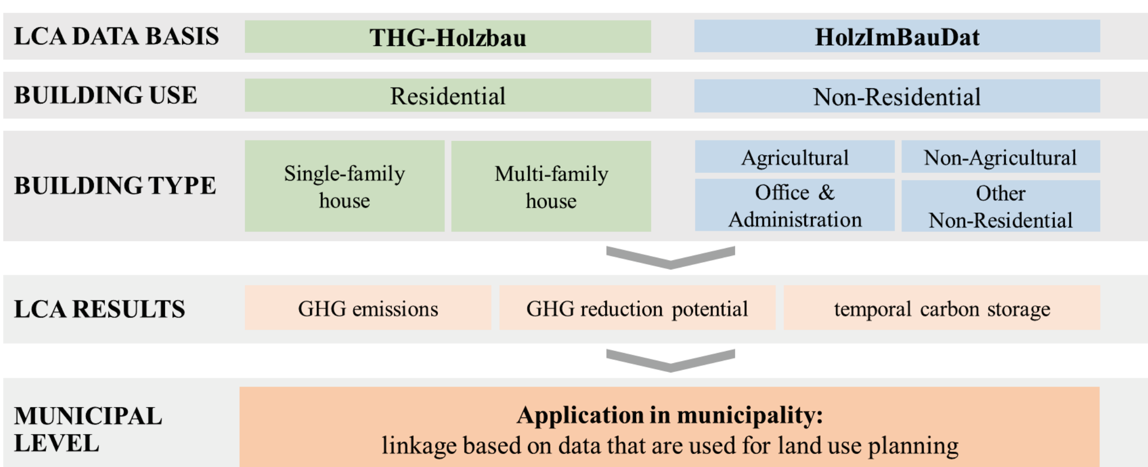

Figure 2. *Methodical structure, data basis and differentiations of the "new construction" scenario*

3.2 REFURBISHMENT

The following section will discuss the refurbishment of the municipal building stock. In detail, the scenario focuses on the energy-efficient refurbishment of the existing residential buildings. To provide a holistic and comprehensive tool for the municipality, it is essential to consider current issues such as the refurbishment of the building stock regarding climate protection measures related to the building sector. More precisely, refurbishment can be considered as a climate and environmentally friendly approach to reduce operating energy consumption at the municipal level. In addition, environmental aspects will become more prominent in public construction projects and their tendering. [26]

Figure 3 highlights the different elements and methods that characterize this refurbishment scenario. Starting with the left-hand element of Figure 3, various "geospatial data" were provided, already processed, and compiled by Geodata-Management, mentioned in Chapter 2.

One of the main features of a building is its geometric characteristic. Taking the outline of a building, the footprint of a building can be calculated. The representation in a three-dimensional format [27] allows the determination of further geometric data of the buildings, such as height, sloping roof surfaces or the building exterior surfaces. The building use is important for the differentiation between residential and non-residential buildings, which show differences in terms of structure and operating energy, among other things. Here, only the residential buildings are considered, since for these, the research results are more advanced and valid than for the heterogeneous non-residential building stock. The building type (single-family house, row house, multi-family house, etc.) is another aspect that is important for assessing the refurbishment potential. The building age is one more important feature for estimating the refurbishment potential. The GHG reduction potential increases with the age of the building because, in contrast, the materials and techniques applied in buildings have continuously gained in efficiency.

Since not every building is equally suitable for refurbishment, distinctions must be drawn between the type and age of residential buildings. Here, the differentiation bases on the German residential building typology of the Institute for Housing and Environment – Institut Wohnen und Umwelt GmbH (IWU) [28]. The term building typology contains several aspects, including the building's age, size, construction method and material, which can be identified for typical structures in certain architectural periods. The building typology represents a methodical classification of residential buildings into certain building age categories and building types based on technical, structural, and energy-relevant characteristics, which results in a national building type matrix. According to IWU, a building typology is a combination of defining these characteristics, groupings of individual buildings and the illustration of representative features with the help of exemplary buildings, which simplifies the energy evaluation of the buildings. [28] In order to provide decision guidance, the German residential building typology of IWU offers two refurbishment scenarios which are assigned to each of the exemplary buildings. These two standards correspond to the energy savings regulation EnEV 2014 [29] and the passive house standard [30]. Exemplary refurbishment measures are also indicated for the individual building elements, such as the external walls, roof, top floor ceiling, among others. In addition, the environmental impact of heating and hot water consumption is given for each exemplary building, for the current energy standard, but also for the refurbishment measures. [28]

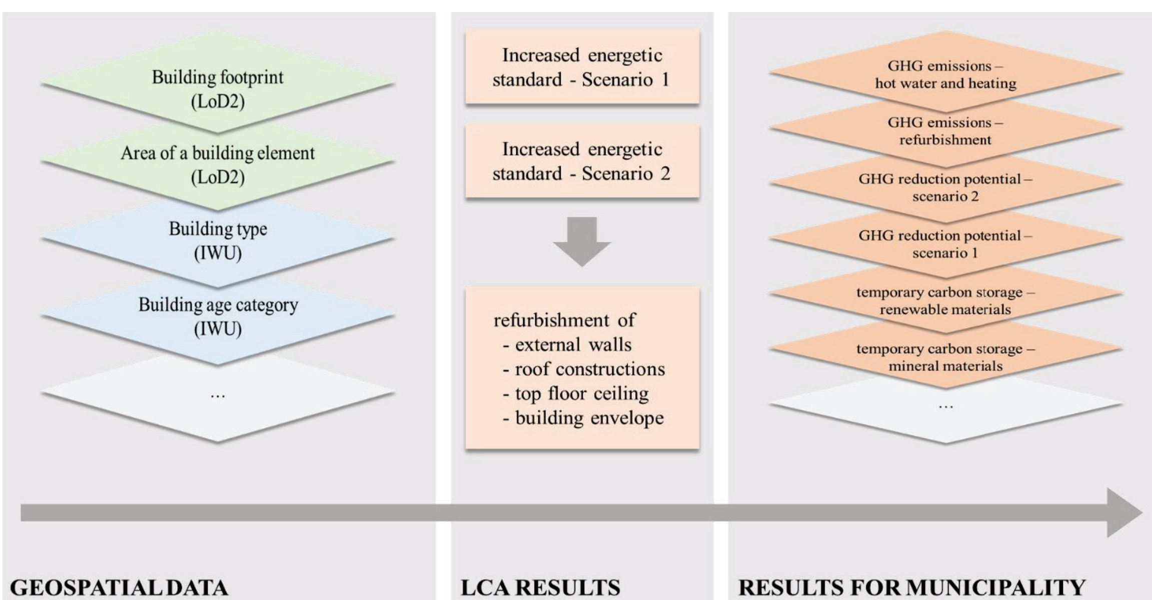

Figure 3. *Methodical structure, geospatial data and LCA procedures of the "refurbishment" scenario*

https://doi.org/10.52202/069179-0521

In case of Holzbau-GIS, an algorithm was developed, which automatically assigns the national building type matrix of the German residential building typology to the buildings in Menden using an iterative process and various geospatial data. Verification showed a high level of agreement, resulting in the continued implementation of this method. As a result, each residential building in Menden is assigned a building type, which is important as a main parameter for transferring the refurbishment potential to Menden. The building age was also identified with great effort for the entire building stock in Menden. More information on the procedure can be found in Menz et al. [31].

Continuing with the second element of the refurbishment scenario in Figure 3, the surface area of building elements, such as the external walls, roof, top floor ceiling or the exterior surface of the whole building envelope were calculated. Therewith, the geospatial data now provides enough information to apply "LCA results" of refurbishment measures to the building stock of Menden (Sauerland) utilizing the German residential building typology. The subsection 3.2.1 focuses on LCA methodology of refurbishment measures at the municipal level.

Analogous to the new construction scenario, various "results for the municipality" are provided: (1) GHG emissions for refurbishment measures constructed with timber or mineral materials (2) GHG reduction potential by replacing mineral structures with wooden structures and (3) temporary carbon storage of the implemented renewable building materials. Further results can be found in Figure 3 in the right-hand element.

3.2.1 LCA of refurbishment measures.

The following subsection focuses on LCA methodology of refurbishment measures at the municipal level. To explain the methodology further, it is necessary to give a more detailed account of LCA for refurbishments in the following section.

There is no common scientific consensus in the literature regarding the actual implementation of LCA for refurbishment measures. [32, 33] Consequently, a coherent LCA approach is needed for refurbishment measures as well as an extension of the framework to the municipal level.

Refurbishment measures are defined as changes to the structural substance of the exterior envelope of the building as well as to the technical installations of the building. [23]

For a municipal level of consideration, structural and material changes are primarily applied to the exterior walls, the roof, or the top ceiling of the building. The replacement of the building's cooling or heating system is also considered an energetic refurbishment but is usually covered at the municipal level by literature values and extrapolations.

Figure 4 displays the framework for LCA of refurbishment at municipal level. The scale of the municipality is not significant in the methodology, as the LCA of refurbishment measures is applied via extrapolations to the municipal level. The LCA is realized using a bottom-up approach for the building components, mainly the exterior building envelope, highlighted colourful in Figure 4. The buildings of the national building type matrix of IWU [28] have been included, whereas they differ in building type and age, indicated in Figure 4 with the colour subdivision of the building symbols.

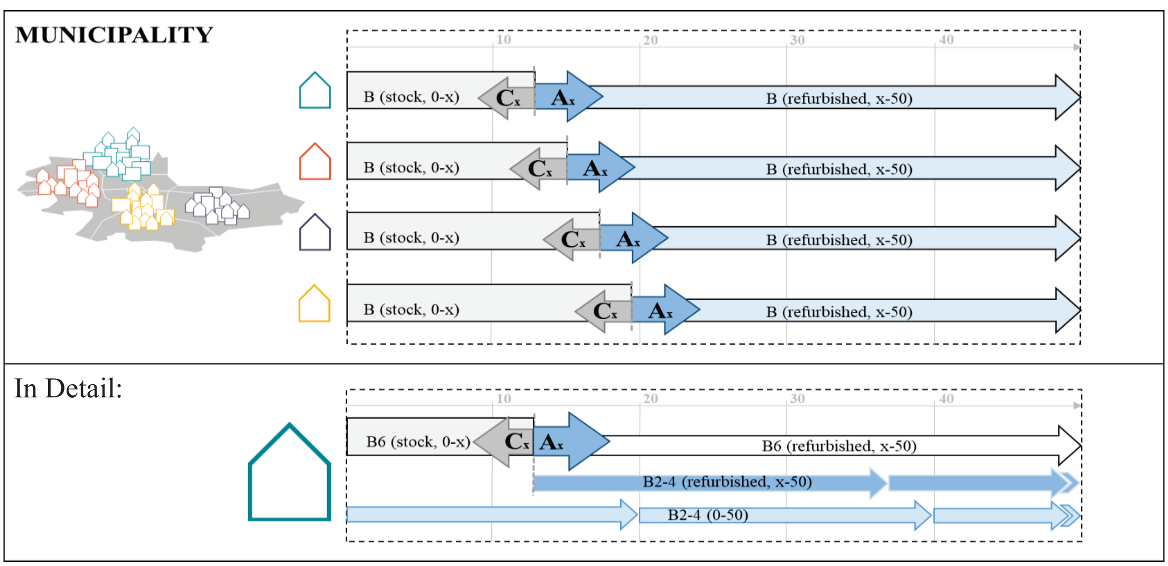

Figure 4. Framework for LCA of refurbishment measures at municipal level – residential buildings categorized in building type and age (colour scheme) – module A includes production A1-A3 - module B includes maintenance B2, replacement B4 and operational energy consumption B6 – module C includes End-of-Life C1-C4

The general framework for LCA of refurbishment at municipal level starts with these parameters:

- objects of assessment: building components
- system boundary: exterior envelope components
- Functional equivalent: 1 m² GEA
- reference study period: 50 years

Following DIN EN 15978:2011 [19] and DIN prEN 15978:2021 [34], the production and transport of all new building components and the disposal of removed components of any necessary construction measures are a part of this methodological approach, disregarding the actual time of refurbishment, see Figure 4.

Now, moving into the details of the LCA methodology for refurbishment, the starting point is year 0 of the reference study period. Here, the modules maintenance B2(0-x), replacement B4(x-0) and operational energy consumption B6(0-x) of the exterior building envelope are applied in the LCA approach. The moment within the reference study period where the refurbishment is executed, is symbolized with an x in Figure 4 of the LCA framework. Now, the life cycle phases for the refurbishment components will be supplemented. The modules End-of-Life C1-C4(x) will be added for the exterior envelope components that have to be demolished due to the refurbishment. Analogously, the modules production A1-A3(x) are included for the newly added building materials. At time x, the refurbishment is completed, the modules maintenance B2(x-50) and replacement B4(x-50) are additionally applied for the new exterior envelope components. In contrast, the modules maintenance B2(0-50) and replacement B4(0-50) of in-situ building components do not change during the refurbishment and therefore remain consistent since year 0. The operational energy consumption B6(x-50) continues as part of the LCA after the refurbishment but is reduced according to the now existing energetic standard to include the impacts of the refurbishment. By the end of the reference study period of 50 years, it is assumed that the municipality being studied will not be demolished leaving the existing buildings in place. As a result, the modules End-of-Life C1-C4(50) and Benefits and Loads D are not considered in the LCA framework.

Referring to Figure 4, the LCA approach is adapted to the spatial context of the municipality. Here, the German residential building typology of the IWU [28] provides the input for the LCA of the exterior envelope of municipal buildings. As mentioned before, the typology offers descriptions of the example buildings, including information on refurbishment options with data on the structure of the building envelope before and after refurbishment measures. With this information, the LCA of the exterior building envelope can proceed as described. Therefore, two linking parameters are used for extrapolation: the German residential building typology and the area of the building envelope components. Using the national building type matrix, a reference to the building stock in Menden can be established. Using the area of the building envelope components, the results of the LCA for refurbishment of the building envelope can be extrapolated. Then, the calculations can be performed for the entire municipality using the m² GEA for the residential buildings.

The material choice for the refurbishment can also be considered and compared within the LCA framework. In this way, the carbon storage can be accounted for each refurbishment approach. Additionally, by comparing different materials with the same measure, GHG reductions due to the material choice can be reported.

In this subsection, it was explained that the methodology requires a new approach for LCA of refurbishments. The following section deals with the demonstration of the results.

4 ILLUSTRATIVE EXAMPLES

In this section, some impressions and first results of the new construction scenario and refurbishment scenario within the web-GIS system Holzbau-GIS are presented.

After the initial log-in procedure, the user sees a short introduction page in the web interface and a view of a basic map of the research area of the sample municipality of Menden (Sauerland). Now, the user can select the topics of interest via a menu tree:

General data (Basisdaten): This category contains general building-specific information on the building stock, such as the building type or the building age, that was compiled by the project partners. [35]

Spatial overall planning (Räumliche Gesamtplanung): The spatial overall planning is subdivided into the categories of urban land use planning, specialized planning, and protected areas. Here, the forest inventory, nature reserves and biotopes are displayed. Among others, these issues are crucial for a comprehensive urban planning process.

Calculation scenarios (Berechnungsszenarien): There are two levels of consideration within the framework of Holzbau-GIS: new construction case studies of already passed development plans (what could have been...?) and GHG reduction potentials if the municipal residential building stock is energetically refurbished. The GHG emissions, GHG reduction potentials and temporary carbon storage are quantified and can be visualized in the web-GIS system.

In Figure 5, data of the the folder environmental planning (Fachplanungen) and subfolders forest (Wald) are shown. The map view of Figure 5 contains a range of different geodata like forest type (Waldart) and forest function (Waldfunktion). The forest type ist categorized in hardwood and softwood. Depending on the formation of the forest types, the category changes. The forest function gives information on recreation, emssion, climate or noise protection of the different forest areas.

https://doi.org/10.52202/069179-0521

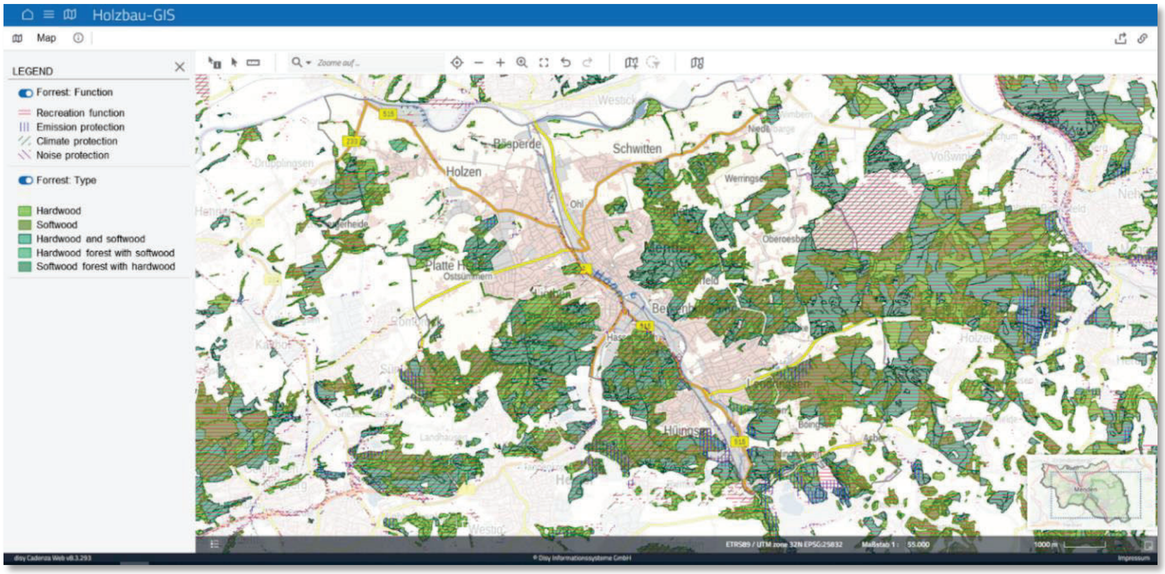

Figure 5: *Display of web-tool Holzbau-GIS: environmental planning*

4.1 NEW CONSTRUCTION

In Figure 6, the web interface shows a dashboard view, customised to the user's individual requirements as well as considering the presented data. Here, the dashbord includes a map view, two charts and a overall sum of one selected resulting parameter.

Figure 6 contains a component of the new construction scenario. A case study approach was chosen to gain a detailed understanding regarding the impact of material choices and to provide detailed illustrations of quantitative GHG reduction potentials and temporary carbon storage for new constructions mesures. This component of the new construction scenario gives an overview of five case studies, exemplifying new constructions in Menden (Sauerland). Development plans contain information on the permitted land uses and building types, as well as further information on permitted building characteristics. The development plans of the five case studies differ in terms of land uses and building types. [36, 37]

In Figure 6 the case study no. 221 as one of the five case studies is displayed. [38] The map view shows the location of the future construction areas according to the development plan no. 221. Within development plan no. 221 for eight construction areas, single-family houses (SFH) were permitted, visible via map view (white).

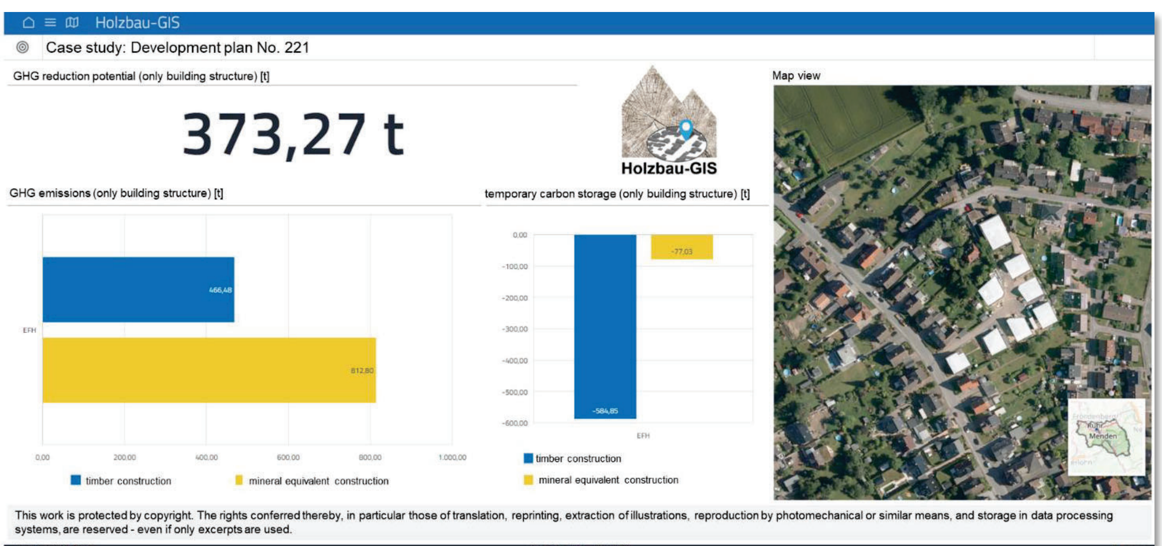

Figure 6: *Display of web-tool Holzbau-GIS: new construction*

The differences between the construction methods of the new building structure are highlighted in the left-hand chart in Figure 6. It shows the GHG emissions [t CO2-Eq.] for each construction method for the maximum permitted GEA, for the corresponding building type.

If the building structure of the SFHs will be a timber construction (blue), the GHG emissions will be at 466.48 t CO2-Eq. If the building structure of the SFHs will be built as a mineral construction (yellow), the GHG emissions will be about 812.80 t CO2-Eq.

The sum of total GHG reduction potential is additionally indicated as an absolute value in the dashboard. Overall, around 373 t CO2-Eq. GHG emissions could be saved for development plan 221.

The right-hand chart shows additional data about the temporary carbon storage for new constructions mesures. If the building structure of the SFHs will be a timber construction (blue), the temporary carbon storage will be at -584.85 t CO2-Eq. If the building structure of the SFHs will be built as a mineral construction (yellow), the temporary carbon storage will be about -77.03 t CO2-Eq.

4.2 REFURBISHMENT

For the refurbishment scenario, the GHG reduction potential is divided into two components: the GHG reduction potential from thermal refurbishment to passive house standard is given within this scenario. In this case, the GHG reduction potentials refer to the CO_2 emissions from heating and hot water. The second component includes the GHG reduction potentials by using timber for the refurbishment instead or mineral materials, that are illustrated in the web-tool Holzbau-GIS and shown in Figure 7. Here, the dashbord includes a map view and a chart. The dashboard displays the refurbishment potential of the municipality of Menden (Sauerland) subdivided into district specific data.

The map view contains the boundaries of the districts with additional data given as pie charts. These charts provide information on the GHG reduction potentials in percentage due to the refurbishment of the whole building envelopes, classified by the residential building type. The overall GHG reduction potential of the district is given within the pie chart, again in percentage. The pie charts display the GHG reduction potential for single-family houses (blue), row houses (yellow), multi-family houses (green), and large multi-family houses (not visible due to the small amount and consequently impact) for each district.

The right-hand chart of Figure 7 contains information as well on the GHG reduction potentials due to the refurbishment of the whole building envelopes, classified by the residential building type. Now the results are given as absolute values in t CO2-Eq. The GHG reduction potential are split by each district, giving summed-up results for single-family houses (blue), row houses (green), multi-family houses (yellow), and large multi-family houses (pink) for each district.

In Lendringsen, for example, a total GHG reduction potential of 6 660.71 t CO2-Eq. is given, if the whole building stock of this district is refurbished to passive house standard. Considering the SHFs, a GHG reduction potential of 4 146.01 t CO2-Eq. is provided for Lendringsen. Referring to the left-hand map view, these buildings generate 12.23 % less GHG emissions if the refurbishment measures are realized using renewable building materials.

In summary, these results show that the web-GIS system can provide different analysis capabilities and levels of analytical complexity for the presented data. By quantifying GHG emissions, GHG reduction potentials, and temporary carbon storage, differences resulting from building type, reference area, and material choice can be highlighted.

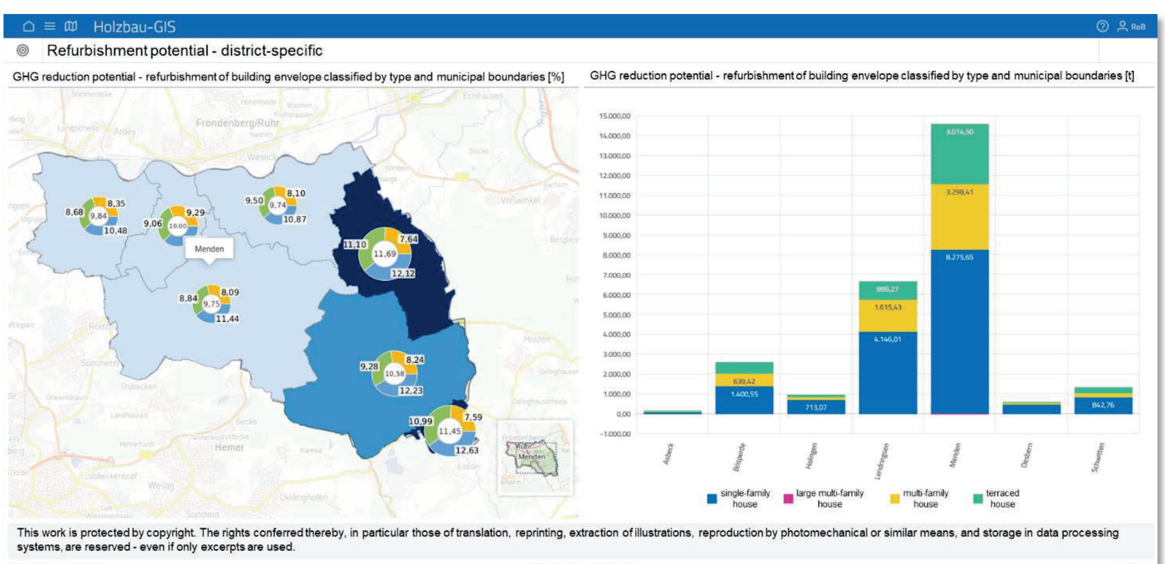

Figure 7: *Display of web-tool Holzbau-GIS: refurbishment*

https://doi.org/10.52202/069179-0521

5 IMPACT

In summary, there are two levels of consideration within the framework of Holzbau-GIS: new construction case studies of already passed development plans (what could have been...?) and GHG reduction potentials if the municipal residential building stock is energetically refurbished. The GHG emissions, GHG reduction potentials and temporary carbon storage are quantified and can be visualized in the web-GIS system. This creates an initial successful combination of geospatial data with LCA data for new construction and refurbishment. The LCAs of refurbishment measures represent a novelty in research which not only satisfies methodologically, but also generates significant LCA outcomes.

Starting with the new building scenario, this study establishes a quantitative framework for an extrapolation of valid building specific LCA data on a municipal scale, subdivided into different land uses and building types.

Referring to the refurbishment scenario, it was necessary to introduce a new methodology for LCA of refurbishment measures. For the implementation of the LCA the German residential building typology of the IWU [28] has been applied. In addition, for the first time, the data for the refurbishment measures of the residential building typology of the IWU were combined with practice-oriented building component structures and material quantities to perform the LCA.

Together, the current data highlights the importance of valid extrapolation to generate an initial estimation of potential GHG reductions at the municipal level. The focus in this context is on reducing environmental pollution and protecting resources, but also on utilizing the carbon storage capacity of renewable raw materials. Additionally, further provided data, e.g. the urban land use planning, support decision-making processes or planning measures for climate protection in urban areas.

6 CONCLUSIONS

The aim of the present study was to serve as a representative calculation to demonstrate the potential of timber construction to the decision makers of a municipality. The web-GIS system "Holzbau-GIS" enables a quantitative analysis of GHG reduction potentials for new buildings and refurbishment measures based on the city of Menden as a case model. The web-GIS system examines the impacts resulting from the use of renewable materials in the building sector at the municipal level. Consequently, we investigate the influence of various materials utilised during constructing new buildings or refurbishing existing ones.

However, these data should be interpreted with caution as certain assumptions must be applied. For an individual building, the calculated data is limited in its preciseness since various calculations were based on average values for standardized building types. A case-by-case assessment remains crucial in order obtain building-related information. To quantify the GHG reductions for a specific building, a comprehensive LCA should be considered in each case.

Regarding the significant role of refurbishment measures for the achievement of climate protection targets, it is necessary to use their potential as far as feasible. In other words, a high level of energy-efficient refurbishment is as essential as an increase of the refurbishment rate. [39]

Referring to the new construction scenario, with the assistance of an online application, users can determine data for future new construction projects. By entering the land use type, building use type, and proposed building type along with the corresponding GEA, the GHG emissions, GHG reduction potential, and temporary carbon storage can be projected. Further development should be pursued in the future to allow an open access tool available to the German municipalities to enable a large application.

The tool supports the sustainable and holistic transformation of the municipal building stock and offers different stakeholders and authorities the possibility to evaluate the environmental quality of refurbishment measures or new construction projects.

In future, we expect criteria such as GHG reduction potentials to play an increasing role when municipal projects will apply for funding.

Overall, constructing with timber, will take an important role regarding climate protection for the building sector, as suggested in the European Union Green Deal [40] and the European Bauhaus Initiative [41]. In this context, the "Holzbau-GIS" can support municipalities by integrating renewable materials as an additional option in their municipal climate protection concept.

Especially on a larger scale, carbon storage through technologies in and on buildings should be taken into consideration in the built environment. [39]

ACKNOWLEDGEMENT

This study was carried out based on the research project “Holzbau-GIS: Reduction of greenhouse gas emissions by building and renovating with wood” funded by the Federal Ministry of Food and Agriculture (BMEL) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Waldklimafonds. The authors gratefully acknowledge the assistance of all concerned.

REFERENCES

[1] Büchner H.: Rechtliche Grundlagen kommunaler Selbstverwaltung. München. 2020

[2] Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection: Climate Action Plan 2050. Berlin. 2016

[3] Federal Ministry for Economic Affairs and Energy: Energy Efficiency Strategy for Buildings. Berlin. 2015

[4] Verbücheln M., Pichl J., Bunzel A., et al.: Stadtplanung und Stadtentwicklung als Hebel für den Ressourcen- und Klimaschutz. Dessau-Roßlau. 2021

[5] Paar A., Bergk F., Dingeldey M., et al.: Klimaschutzpotenziale in Kommunen. Dessau-Roßlau. 2022

[6] Hafner A., Slabik S., Storck M.: Urban Site Development as Temporal Carbon Storage—A Case Study in Germany. *Sustainability*, 12(14):5827. 2020

https://doi.org/10.52202/069179-0521

[7] Bürger V., Hesse T., Palzer A., et al.: Klimaneutraler Gebäudebestand 2050. Dessau-Roßlau. 2017

[8] Hecht R.: Automatische Klassifizierung von Gebäudegrundrissen. Rhombos-Verl., Berlin. 2014

[9] Hafner A., Schäfer S.: Comparative LCA study of different timber and mineral buildings and calculation method for substitution factors on building level. *Journal of Cleaner Production*, 167:630–642. 2017

[10] Hafner A., Rüter S.: Method for assessing the national implications of environmental impacts from timber buildings. *Wood and Fiber Science*, 50(Special):139–154. 2018

[11] Hafner A.: Klimaschutz und Holzbau. *AFZ-DerWald*, 21:33-35. 2017

[12] Turek T., Stępniak C.: Areas of Integration of GIS Technology and Smart City Tools. Research findings. *Procedia Computer Science*, 192(2):4681–4690. 2021

[13] Keppner B., Kahlenborn W., Libbe J., et al.: Direkte und indirekte Umwelteffekte von intelligenten, vernetzten urbanen Infrastrukturen. Dessau-Roßlau. 2022

[14] Bartelme N.: Geoinformatik. Springer Berlin, Heidelberg. 2005

[15] Bill R.: Grundlagen der Geo-Informationssysteme. Wichmann, Berlin. 2010

[16] Bill R.: Grundlagen der Geo-Informationssysteme. Wichmann, Berlin. 2016

[17] Harzer C.: GIS-Report 2018/19. Karlsruhe. 2018

[18] Stockwald M.: Geoinformationssysteme. Bayer. Staatsministerium der Finanzen, München. 2003

[19] EN 15978:2011, Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method. Beuth Verlag GmbH, Berlin, 2012.

[20] Hafner A., Özdemir Ö.: Comparative LCA study of wood and mineral non-residential buildings in Germany and related substitution potential. *Eur. J. Wood Prod.*, 81(1):1–16. 2022

[21] Hafner A., Rüter S., Schäfer S., et al.: Treibhausgasbilanzierung von Holzgebäuden. Waldklimafonds, BMEL/BMUB. 2017

[22] Hafner A., Özdemir Ö.: HolzimBauDat: Datenbasis zur Bewertung einer Nachhaltigen und Effizienten Holzverwendung im deutschen Bausektor. FNR, BMEL. 2020

[23] Slabik S., Zernicke C., Storck M., et al.: A Methodological Approach for Life Cycle Assessment of Refurbishment Measures – From Building to Neighbourhood and Municipal Level. In: *Central Europe towards Sustainable Building 2022 (CESB22). (currently being published)*. 2022

[24] Slabik S., Storck M., Zernicke C., et al.: Proposing an LCA methodology for the assessment of neighbourhood refurbishment measures. *Environmental Research: Infrastructure and Sustainability*, 3(1). 2023

[25] Disy Informationssysteme GmbH: Treibhausgase einsparen durch Holzbauweise. Disy entwickelt mit der Ruhr- Universität Bochum ein „Holzbau-GIS". Karlsruhe. 28.08.2020

[26] Federal Ministry of Food and Agriculture: Mitigating climate change. Creating value. Utilising resources efficiently. Bonn. 2021

[27] Bezirksregierung Köln (Ed.): 3D-Gebäudemodelle. www.bezreg-koeln.nrw.de/brk_internet/geobasis/3d_gebaeudemodelle/index.html, (accessed 2022-10-25).

[28] Loga T., Stein B., Diefenbach N., et al.: Deutsche Wohngebäudetypologie. Institut Wohnen und Umwelt GmbH, Darmstadt. 2015

[29] Institut für Energie-Effiziente Architektur mit Internet-Medien (Ed.): Energieeinsparverordnung - EnEV 2014. www.enev-online.com/enev_2014_volltext/, (accessed 2022-10-25).

[30] Heinze GmbH | NL Berlin | BauNetz (Ed.): Glossar - Passivhausstandard. www.baunetzwissen.de/glossar/p/passivhausstandard-3119421, (accessed 2022-10-25).

[31] Menz P., Jolk C., Zernicke C., et al.: Ermittlung und Überprüfung der Datengrundlage für das Modell zur Einsparung von Treibhausgasen durch stoffliche Holznutzung im Bauwesen im Holzbau-GIS für die Stadt Menden. In Fuchs-Kittowski F., Abecker A., Hosenfeld F., Ortleb H., Klafft M. (Eds.), *Umweltinformationssysteme – Vielfalt, Offenheit, Komplexität (currently being published).* Springer Vieweg. 2023

[32] Cabeza L.F., Rincón L., Vilariño V., et al.: Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. *Renewable and Sustainable Energy Reviews*, 29:394–416. 2014

[33] Vilches A., Garcia-Martinez A., Sanchez-Montañes B.: Life cycle assessment (LCA) of building refurbishment: A literature review. *Energy and Buildings*, 135:286–301. 2017

[34] prEN 15978-1:2021, Sustainability of construction works - Methodology for the assessment of performance of buildings - Part 1: Environmental Performance; German and English version. Beuth Verlag GmbH, Berlin, 2021.

[35] Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (Ed.): Amtliches Liegenschaftskatasterinformationssystem. www.adv-online.de/AdV-Produkte/Liegenschaftskataster/ALKIS/, (accessed 2022-10-25).

[36] Abteilung für Planung und Bauordnung der Stadt Menden (Ed.): Bebauungspläne der Stadt Menden (Sauerland). www.menden.de/leben-in-menden/stadtplanung-bauen-verkehr/stadtplanung-1/bebauungsplaene-und-satzungen, (accessed 2022-10-25).

[37] Märkischer Kreis (Ed.): Open Data - Märkischer Kreis. gdi2.maerkischer-kreis.de/opendata.html, (accessed 2022-10-25).

[38] Zernicke C., Mattes C., Jolk C., et al.: Holzbau-GIS: Presenting first results of GIS-based modelling on reduction of greenhouse gas emissions, through construction and renovating with timber, on a municipal level. In: *Ecocity World Summit 2021-22 Conference Proceedings*. 2022

[39] Kuittinen M., Zernicke C., Slabik S., et al.: How can carbon be stored in the built environment? A review of potential options. *Architectural Science Review*, 65(1):1–17. 2021

[40] European Commision (Ed.): The European Green Deal. ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_de, (accessed 2022-10-25).

[41] European Union (Ed.): New European Bauhaus. europa.eu/new-european-bauhaus/index_en, (accessed 2022-10-25).

 https://doi.org/10.52202/069179-0521