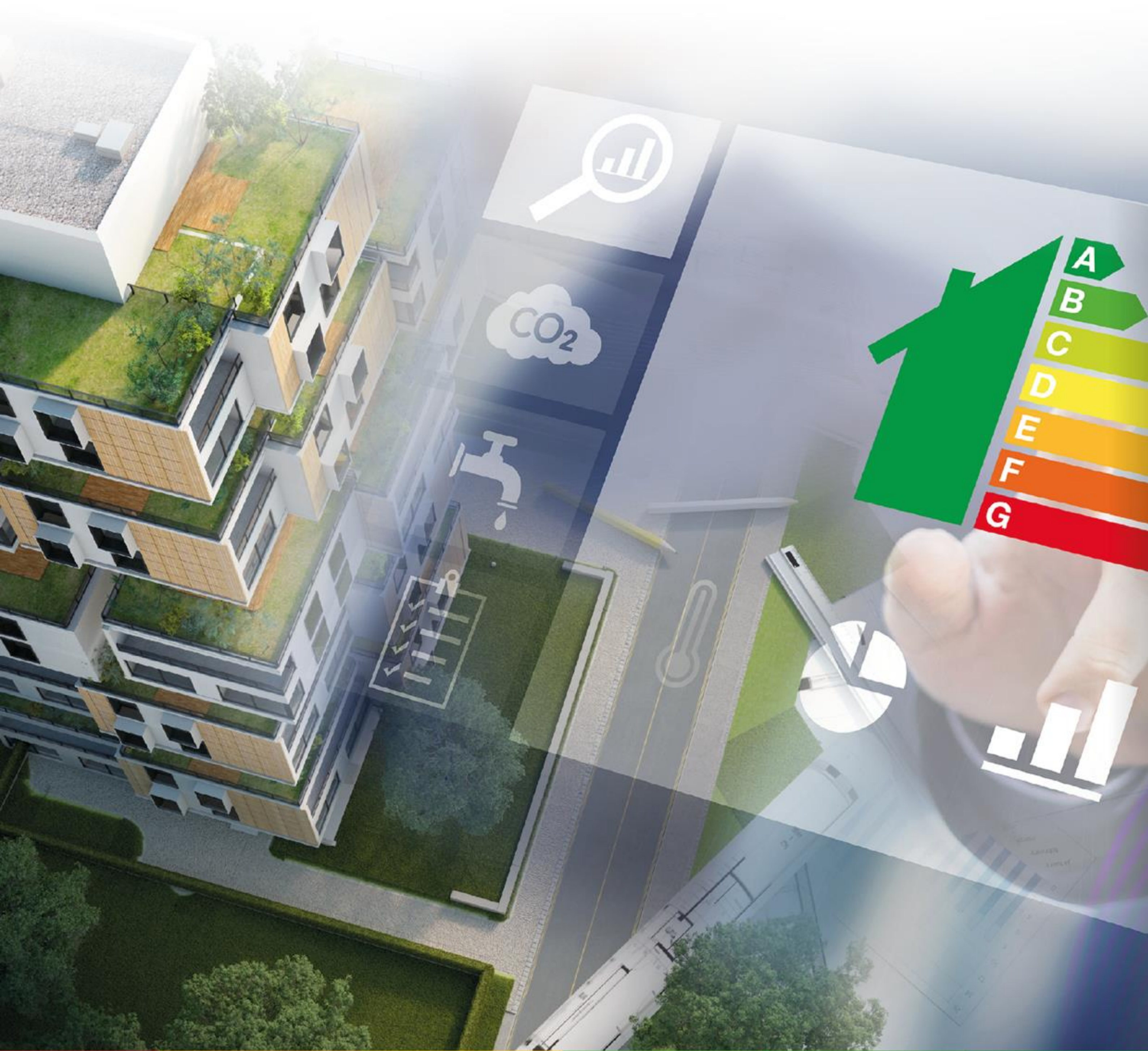
D2.2 Asset assessment methodology in complex level



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Asset methodology assessment in building complex level v1

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Executive Summary

This deliverable comprises five chapters, each contributing insights to the development of an asset methodology for complex buildings scale. Chapter 1 serves as an introduction, outlining the objectives and scope of the deliverable, aligned with the Grant Agreement proposal. Chapter 2 offers an extensive review of 50 Urban Sustainability Frameworks, 40 Neighborhood Sustainability Assessment tools, and the five 'overarching' EPB standards (ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1). Additionally, a thorough analysis of the most frequent indicators of sustainability is highlighted. In Chapter 3, the aim to identify Energy-Consuming Services on a Neighbourhood Scale. This leads to the proposal of a comprehensive classification of energy-consuming services at the neighbourhood scale. Chapter 4 delves into a discussion surrounding the concepts of Energy Communities and Smart Grids, providing critical insights into their significance for the overall operational methodology. The central theme of Chapter 5 presents the criteria for defining a Neighbourhood Classification, offering guidelines for the appropriate corrections and adaptations for delimitating the assessment area to evaluate the energy consumption. The extensive review of existing frameworks, tools, and standards ensures a solid foundation for the proposed operational methodology. This deliverable lays the groundwork for future advancements in the development of an Energy Performance Certificate for neighbourhood scale.

Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

Term	Description
AD	Architectural Design
ASGE	Assessment Standard for Green Eco-districts
CDP	Community Detailed Plan
CEP	Community Energy Planning
CEP	Comprehensive Energy Planning
CESD	Comprehensive Energy System Design
CMP	Community Master Plan
CRP	Community Regulatory Plan
CSP	Community Site Plan
DSM	Demand-side management
ECI	Energy consumption indicator
EeMAP	European Regional Network of the World Green Buildings Council for the Energy
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
GIS	Geographic Information System
GTI	Green Township Index
HVAC	Heating, Ventilation, and Air Conditioning
IRP	Integrated renewable and non-renewable energy resource planning
LCA	Life Cycle Analysis
LP and NLP	Linear Programming (LP) and Non-Linear Programming
MILP	Mixed-integer programming
MP	Municipal facility plans
MSs	Member States
NSA	Neighbourhood sustainability assessment
PEP	Primary energy planning
SA, GA, TS, ES, ANN, ACO, PSO	Simulated Annealing (SA), Genetic Algorithms (GA), Tabu Search (TS), Evolution Strategies (ES), Artificial Neural Networks (ANN), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO)
SRI	Smart Readiness Indicator

1 Introduction

The project aspires to develop a new rating scheme for neighbourhood scale, based on the assessment of individual building units and additional building complex parameters with the aim of energy performance certification of building complexes. The energy infrastructure and services on a building block scale, as well as the interaction of the block buildings, were studied. During this task, the differences that the building had in relation to the neighbourhood (street lighting, network services, smart grids, energy communities, etc.) were determined. Another aspect that was investigated was how buildings interacted with each other at a neighbourhood level and how this interaction affected the energy performance from that perspective. Deliverable D2.2 presents the main aspects of the asset complex EPCs, identifying the required conditions, the calculation input, as well as the prescribed results of building complex EPCs.

1.1 Background and Objectives

The main objective of this deliverable is:

The development of a new rating scheme for neighbourhood scale, based on the assessment of individual building units and additional building complex parameters.

The secondary objectives are:

- Shifting from the unit building scale to the complex building scale,
- Exploring the interaction between buildings,
- Identifying energy-consuming services unique to neighbourhoods,
- Creating a neighbourhood certificate.

1.2 Scope of the deliverable

As we move into an era, where building units will be able to interact energetically through smart grids but also through energy communities, energy classification on a neighbourhood scale is expected to become particularly important in the coming years. SmartLivingEPC will launch and introduce a new energy classification methodology at the neighbourhood level, which on the one hand will be based on the categorization of individual building units, on the other hand, will consider the energy infrastructure and services on a district scale, as well as the interaction of buildings. The result is expected to be a certificate at a complex level, which will allow energy savings at the level of neighbourhood energy infrastructure. The SmartLivingEPC complex certification scheme will be demonstrated in the district of Leitza, Spain where 6 buildings nearby have been selected.

2 Current Neighbourhood Scale Assessment Schemes

2.1 Overview of Existing Assessment Schemes

Since their creation, the EPCs have been limited to representing a rating scheme that summarizes the energy performance of buildings. However, other evaluation systems, whose reference frameworks are based on the concept of sustainability rather than energy, have expanded their scope. The neighborhood sustainability assessment tools emerged from the need to assess and improve the sustainability performance of urban areas. These tools aim to provide a systematic and holistic evaluation of various aspects of sustainability, including environmental, social, economic, and cultural factors. By assessing these factors, neighborhood sustainability assessment tools help identify strengths, weaknesses, and areas for improvement in order to promote sustainable development practices.

On the other hand, urban sustainability frameworks provide a broader perspective by focusing on sustainability at the urban scale. These frameworks can provide a roadmap for planning, designing, and managing cities in a way that promotes sustainability and resilience. Both neighborhood sustainability assessment tools and urban sustainability frameworks serve as valuable resources for policymakers, urban planners, architects, and developers in their efforts to create more sustainable and liveable neighborhoods and cities. These tools and frameworks help guide decision-making processes, inform policy development, and encourage the adoption of sustainable practices in urban development projects.

In a study carried out by Michalina [1], the authors present a review of 50 Urban Sustainability Frameworks. The goal of his study was to select the most relevant indicators for each framework, analyze their content in terms of basic structure (dimensions, thematic categories, indicators), and identify current trends and challenges in the domain of urban sustainability assessment. Table 1 below presents the list of the analyzed urban sustainability frameworks.

Table 1: List urban sustainability frameworks

Framework	Organisation	Locations	Year
Sustainable Cities Index	Arcadis	Cities around the world	2018
SDG-Indikatoren für Kommunen	Bertelsmann Stiftung, German Institute of Urban Affairs, BBSR, DLT, DST, DStGB, SKEW	Cities in Germany	2018
Global indicator framework for the SDGs	UNSD (IAEG-SDGs)	Cities around the world	2017
One Planet Living (One Planet Cities)	Bioregional	Cities around the world	2017
The methodology for evaluating sustainable development of small towns	Healthy Cities, Towns, and Regions of the Czech Republic, Charles University	Cities in the Czech Republic	2017
Nachhaltigkeitsbericht für Ludwigshafen am Rhein	City of Ludwigshafen am Rhein	Ludwigshafen am Rhein	2017
Urban Sustainability Framework	Global Platform for Sustainable Cities (World Bank)	Cities around the world	2016
Monitor Nachhaltige Kommune: Bericht 2016—Teil 1	Bertelsmann Stiftung, German Institute of Urban Affairs	Cities in Germany	2016

Sustainability Evaluation Metric for Policy Recommendations	Environmental Protection Agency (EPA)	Cities in Ireland	2016
Nachhaltigkeitsbericht der Stadt Mannheim	Mannheim, FEST	Mannheim	2016
European Green Leaf	European Commission	Cities in Europe	2015
Indicators to assess cities' livability	Faculty of Engineering, The University of Porto	Cities in Europe	2015
Leitfaden N!-Berichte für Kommunen	FEST—Institut für interdisziplinäre Forschung	Cities in Baden-Württemberg (Germany)	2015
Indicators for City Services and Quality of Life (ISO 37120)	The World Council on City Data	Cities around the world	2014
Urban environmental indicators (Green Growth in Cities)	Green Cities Programme OECD	Cities around the world	2013
Indicators for sustainable development of small towns	Vidzeme University of Applied Sciences, Maynooth University	Valmiera	2013
City Prosperity Index	City Prosperity Initiative (UN-Habitat)	Cities of the world	2012
Toolkit for Cities	Sustainable Cities International	Cities around the world	2012
International Ecocity Framework and Standards	Ecocity Builders	Cities around the world	2012
Urban Sustainability Indicators	Sustainable Cities Program	Cities in Brazil	2012
Milanówek's sustainable development indicators	Jagiellonian University, Warsaw University	Milanówek	2012
Urban Metabolism Framework	European Environment Agency	Cities in Europe	2011
BRIDGE Decision Support System	14 Organisations from 11 EU countries	Cities in Europe	2011
Toolkit for Cities	Government of Canada, Sustainable Cities International	Cities in Canada	2011
CASBEE for Cities	Japan Sustainable Building Consortium (JSBC)	Cities in Japan	2011
The European Green Capital Award	European Commission	Cities in Europe	2010
Indicators of Emerging and Sustainable Cities Initiative	Inter-American Development Bank (IDB)	Cities in Latin American and Caribbean	2010
China Urban Sustainability Index	Urban China Initiative	Cities in China	2010
ACF Sustainable Cities Index	Australian Conservation Foundation (ACF)	Cities in Australia	2010
Green City Index	Siemens	Cities of the world	2009
Global City Indicators	Global City Indicators Facility (U. of Toronto)	Cities of the world	2008
Reference Framework for Sustainable Cities—RFSC	European Commission	Cities in Europe	2008
STAR Community Rating System	STAR Communities, U.S. Green Building Council	Cities in the United States of America	2008

Key Performance Indicators for the Sino-Singapore Tianjin Eco-city	Singapore and Chinese Governments	Sino-Singapore Tianjin Eco-city	2008
Urban Ecosystem Europe	ICLEI, Ambiente Italia	Cities in Europe	2007
Nachhaltigkeitsindikatoren Linzer Agenda 21	City of Linz	Linz	2007
Global Urban Indicators	UN-Habitat	Cities of the world	2006
List of indicators from the project STATUS	European Commission	Cities in Europe	2006
List of indicators from the project TISSUE	European Commission	Cities in Europe	2005
Set of sustainable development indicators for Slovak cities	Regional Environmental Centre Slovakia	Cities in the Slovak Republic	2005
LISL—Lokales Indikatorensystem für dauerhafte Lebensqualität	Upper Austria	Cities in Upper Austria	2004
Sustainability monitoring in the City of Zurich	City of Zurich Urban Development, Department of the Mayor	Zurich	2004
Indikatoren für eine nachhaltige Stadtentwicklung	Office citizen participation and Local Agenda 21, Gießen	Gießen	2004
London's Quality of Life Indicators	London Sustainable Development Commission	London	2004
Cercle Indicateurs	Federal Office for Spatial Development (ARE), Federal Statistical Office	Cities in Switzerland	2003
Hamburger Entwicklungs-INdikatoren Zukunftsfähigkeit	Zukunftsrat Hamburg	Hamburg	2003
European Common Indicators	European Commission	Cities in Europe	2002
Urban Audit Cities Statistics	Eurostat	Cities in Europe	1999
Urban Sustainability Indicators	Eurofound	Cities in Europe	1998
Indicators of Sustainable Community	Sustainable Seattle	Seattle	1993

Source: Michalina, D., Mederly, P., Diefenbaher, H., & Held, B. (2021). Sustainable Urban Development: a review of Urban Sustainability Indicator Frameworks. Sustainability 2021, 13, 9348.

The work shows that the majority of the 50 analysed frameworks covered the three traditional dimensions of sustainability: the environmental, economic, and social, plus the added of an extra dimension, the institutional dimension. Nevertheless, an insufficient representation of the institutional dimension of sustainability was found. Moreover, the authors point that in the assessment process, keeping the balance and the interconnection between the dimensions are important conditions, thus creating a complex urban sustainability assessment system. It should be noted that a dimension is a measure of the complexity of the analysis space and provides information about the minimum amount of information needed to adequately describe it. The categories, on the other hand, narrow the scope of the field of study, allow analyzing and comparing different phenomena to identify patterns, relationships, interdependencies, among other aspects. Finally, the indicators are a measure that represents a specific variable, and must be reliable, valid and representative of the reality to be measured, so that they can provide accurate and relevant information for decision making.

Other authors analysed the most frequent (with a representation of at least 1/3) thematic categories of the selected frameworks from the point of view of the representative indicators, identifying so-called headline or key indicators—they are indicated in almost every framework, or their multiple and frequent presences confirm their importance. They found that the sustainable frameworks also differ in terms of their thematic categories with the arrangement of the indicators. For example, the indicator "share of population connected to a public sewerage system and wastewater treatment system" was included in the "water" category, but also in the "housing" category. The indicator entitled "number of traffic accidents per year per 1000 inhabitants" was included in the "safety and security" category, but also in the "mobility and transport" category. Moreover, in some cases, the indicators were directly assigned to a dimension without being arranged in a thematic category.

Other differences among the indicators' representation were seen between the frameworks of developing states and to those of states considered to be developed, where, in the developed countries, environmental categories and indicators are overrepresented, while in developing countries, there are mostly social and economic categories and indicators. For this reason, it is important to take the relevance of the geographical space into consideration in the selection. Finally, authors conclude that the main issue is the difference between the individual terminologies and the names of some categories, which often differ even though they assess the same domain. For this reason, many authors suggest standardising the terminology of sustainability assessment, which would help to better clarify this issue.

Furthermore, in a systematic literature review conducted by Sharifi [2], the authors identified successes related to the development and implementation of 40 Neighborhood Sustainability Assessment tools. The table below presents the results of the analysis of 117 articles where 40 tools, originating from 18 different countries across the globe, were found (Table 2Table 2).

Table 2: Neighborhood Sustainability Assessment tools.

Tool	Main developer (s)	Origin	Year Latest version
Comprehensive Assessment Method for Sustainable Urban Development (CAMSUD)	Ali-Toudert et al. (2019)	Germany	2019 -
SNM (Successful Neighborhood Model)	author of the paper	South Africa	2019 -
Assessment Standard for Green Eco-districts (ASGE)	Ministry of Housing and Urban-Rural Development of the People's Republic of China	China	2018 -
Green Star SA (South Africa)	Green Building Council South Africa	South Africa	2017 -
Building Environmental Assessment Method (BEAM) Plus Neighborhood Assessment Tool	Hong Kong Green Building Council	Hong Kong (China)	2016 -
Green Rating for Integrated Habitat Assessment (GRIHA LD) GRIHA Council and The Energy and Resources Institute	Council and The Energy and Resources Institute	India	2015 -
Conavi CEV Mexican Code	National Housing Commission	Mexico	2015 -
Living Community Challenge	International Living Future Institute	US	2014 - 2017
Circles of Sustainability	UN Global Compact Cities Programme	Australia	2014 -
EcoQuartier	Ministeres Transition ecologique Coh esion des territoires	France	2012 - 2020
Green Star Communities	Green Building Council Australia (GBCA)	Australia	2012 - 2016
STAR Communities	STAR Communities (now merged with the USGBC)	US	2012 - 2016

DGNB for Districts	German Sustainable Building Council	Germany	2012 -
EcoDistricts	EcoDistricts	US	2012 -
GBI Township	Greenbuildingindex Sdn Bhd (GSB)	Malaysia	2011 -
AQUA Bairro e loteamento label	Fundaçao Vanzolini~	Brazil	2011 -
Pearl Community Rating System	Abu Dhabi Urban Planning Council	UAE	2010 -
2030 Districts	Architecture 2030	US	2010 -
EEWH Assessment System for Eco-community	Architecture and Building Research Institute	Taiwan	2010 -
LEED-ND	US Green Building Council (USGBC)	US	2009 - 2018
BCA Green Mark for districts	Building and Construction Authority (BCA)	Singapore	2009 - 2017
Sustainable Sites Initiative (SITES)	American Society of Landscape Architects	US	2009 - 2015
BREEAM Communities	Building Research Establishment (BRE Global)	UK	2009 - 2012
GreenTRIP	TransForm	US	2008 -
IGBC Green Townships	Indian Green Building Council	India	2008 -
Sustainable Building Tool (SBTool)	International Initiative for a Sustainable Built Environment (iiSBE)	Canada	2007 - 2020
CASBEE-UD	The Institute for Building Environment and Energy Conservation (IBEC)	Japan	2007 - 2014
Global Sustainability Assessment System	Gulf Organization for Research and Development	Qatar	2007 -
Sustainable Community Rating (SCR)	VicUrban, the Victorian Government’s land development agency	Australia	2007 -
EnviroDevelopment	Urban Development Institute of Australia (UDIA)	Australia	2006 -
VicUrban Sustainability Charter (Master Planned Community Assessment Tool)	Government of Victoria	Australia	2006 -
Wulvern Indicators of Neighborhood Sustainability (WINS)	Wulvern	UK	2006 -

Neighborhood Sustainability Framework (NSF)	Beacon Pathway	New Zealand	2005 - 2014
EarthCraft Communities	Greater Atlanta Home Builders Association, the Atlanta Regional Commission, the Urban Land Institute, etc.	US	2005 - 2014
Enterprise Green Communities	Enterprise Community Partners	US	2004 - 2020
One Planet Communities	BioRegional Development Group	UK	2004 -
Ecocity	EU research project	EU	2002 -
HQE2R	Scientific and Technical Center for Building (CSTB)	France	2001 -
SPeAR (Sustainable Project Appraisal Routine)	ARUP	UK	2000 - 2017
Green Township Index	Siew (2018)	Malaysia	No data

Source: Sharifi, A., Dawodu, A., & Cheshmehzangi, A. (2021). Neighborhood sustainability assessment tools: A review of success factors. Journal of Cleaner Production, 293, 125912.

The background of sustainable building certification systems can be traced back to efforts towards sustainability and green construction that emerged in the late 20th century. In their review, Sharifi and his collaborators observed a dominant focus on LEED-ND (launched in 2000 by the US Green Building Council in the United States) and BREEAM Communities (developed in the United Kingdom in 1990) as the primary topics of study. The analysed studies show that one of the major success factors of the neighbourhood sustainability assessment tools (NSA) is the provision of quantifiable indicators, which offer a better understanding of the sustainability performance of neighbourhoods that can result in enhanced communications with stakeholders. For instance, these quantifiable indicators can be used to identify differences between desirable and undesirable sustainability performance in a city and inform decision makers of the state of progress in achieving targets. However, there are also arguments that quantitative indicators of most urban sustainability assessment tools are not suitable for assessing performance against some measures such as happiness, quality of life, sense of place, and aesthetics that are inherently qualitative in nature.

Moreover, structural success of the effectiveness of local tools that are developed by taking into account the local priorities and idiosyncrasies was mentioned, saying that local tools, which are embedded in the planning process perform better in terms of addressing sustainability concerns and providing locally relevant recommendations. Nevertheless, it is also argued that developing and implementing locally-designed tools are data and resource-intensive processes that may not always be feasible, so is arguably one of the main reasons for the better uptake of tools such as LEED-ND and BREEAM Communities that tend to use standardised indicators for assessment across different contexts.

Noteworthy that a common criticism of NSA tools is their failure to account for various economic, environmental, institutional, and social dimensions of sustainability in a balanced manner, emphasising specific dimensions at the expense of others. Specifically, NSA tools have been criticised for overemphasise the environmental dimension of sustainability over other dimensions like social and institutional were underrepresented. In this sense, some recently developed tools such as the Green Township Index (GTI) and Assessment Standard for Green Eco-districts (ASGE) are highlighted in the literature [3, 4] for their success in addressing multiple sustainability dimensions in a balanced manner.

Finally, authors conclude that an important benefit of NSA tools is their utility for achieving co-benefits in terms of resilience, health, and climate change adaptation and mitigation. Energy-efficient design strategies that facilitate indoor and outdoor thermal comfort and reduce energy demand (e.g., passive building and urban design techniques, smart metering systems, etc.) provide health, as well, as climate change mitigation co-benefits, that can increase resilience to various stressors such as extreme heat events and energy shocks. For instance, authors show that incorporating Enterprise Green Communities and LEED standards in low-income housing renovation projects in Washington D.C., improve health and housing conditions.

After reviewing the current state-of-the-art and analyzing urban sustainability frameworks and NSA tools, it is evident that the existing frameworks and tools for evaluating neighborhoods lack a cohesive approach in establishing parameters for urban energy efficiency. The dimensions and indicators proposed in these frameworks and tools tend to focus more on qualitative data collection rather than addressing the evaluation of energy consumption in specific areas of cities.

While the reviewed urban sustainability frameworks provide valuable insights into various dimensions of sustainability, they often lack specific metrics and indicators directly linked to energy consumption. The focus on qualitative factors, such as happiness, quality of life, and aesthetics, while important, may not adequately capture the crucial energy-related aspects that contribute to sustainable urban development. Moreover, the NSA tools examined during our discussion demonstrate a similar trend. While they offer valuable means to assess the overall sustainability performance of neighborhoods, the quantitative indicators related to energy consumption appear to be limited. The dispersion of indicators and the focus on qualitative aspects rather than energy-specific metrics hinder the comprehensive evaluation of energy efficiency within neighborhoods.

To address this gap, future efforts should aim to develop and integrate more robust and standardized energy efficiency indicators into urban sustainability frameworks and NSA tools. By incorporating specific metrics that assess energy consumption patterns, energy-efficient design strategies, and renewable energy integration, these frameworks and tools can provide a more comprehensive and actionable assessment of energy efficiency in urban areas. This, in turn, can guide decision-makers, urban planners, and stakeholders in implementing targeted interventions to enhance energy performance and foster sustainable urban development.

2.2 Evaluation of Neighbourhood Scale Assessment Schemes

To boost the energy performance of buildings, the EU has established a legislative framework that includes the Energy Performance of Buildings Directive 2010/31/EU (EPBD) and the Energy Efficiency Directive 2012/27/EU [5, 6]. Together, both promote policies that will help:

- Achieve a highly energy efficient and decarbonised building stock by 2050
- Create a stable environment for investment decisions
- Enable consumers and businesses to make more informed decisions to save energy and money

In this context, Energy Performance Certificates (EPCs), regulated by the EPBD, are expected to be an important instrument to improve the market adoption of new energy efficient buildings and the energy efficient renovation of existing buildings. These certificates are required in many countries and provide information about the energy consumption and carbon emissions of a building. EPCs primarily focus on energy efficiency and may not necessarily address other aspects of sustainability or environmental quality.

The EPBD lists five EPB standards as 'overarching'. The meaning of the terms 'overarching' in the new EPBD and in the modular structure of the set of EPB standards only partly overlap. In the modular structure the term overarching refers to the standards that deal with the overall energy performance of a building, while other modules deal with the building as such or specific technical building systems or services (M3 etc.) The five 'overarching' EPB standards ISO 52000-1, 52003-1, 52010-1, 52016-1 and 52018-1 [7, 8, 9, 10, 11] have in common that each of these describes an important step in the assessment of the energy performance of building:

- ISO 52000-1 is the overarching EPB standard, providing the general framework of the EPB assessment. It establishes a systematic, comprehensive and modular structure for assessing the energy performance of new and existing buildings (EPB) in a holistic way. It is applicable to the assessment of overall energy use of a building, by measurement or calculation, and the calculation of energy performance in terms of primary energy or other energy-related metrics. It takes into account the specific possibilities and limitations for the different applications, such as building design, new buildings 'as built', and existing buildings in the use phase as well as renovation. It also contains an overview of common terms and definitions and symbols for the whole set of EPB standards.

- ISO 52003-1 provides general insight on how to make good use of the outputs of the set of EPB assessment standards for different purposes (post-processing) in the form of overall and partial EPB indicators. It describes the relation between the EPB indicators and the EPB requirements and EPB ratings. It also includes a couple of possible EPB labels, and it lists the different steps to be taken when establishing an EPB certification scheme.
- ISO 52010-1 contains procedures to assess the climatic data needed as common input or boundary condition for many elements in the energy calculations. For instance, as input for energy and daylighting calculations, for building elements (such as roofs, facades and windows) and for components of technical building systems (such as thermal solar collectors, PV panels). But also, as boundary condition for the performance of specific heating, cooling and ventilation systems.
- ISO 52016-1 provides the procedures to calculate the internal temperatures and energy needs for heating and cooling for the building as such. This is the core of the calculation of the energy use, because many aspects coincide in this calculation: thermal insulation, air tightness and ventilation, the building mass, solar heat load and passive solar energy and internal heat gains (e.g. from lighting). Many countries have introduced or consider introducing specific EPB requirements at the level of ‘the energy needs’ of the building or the ‘skin’ or ‘fabric’ of the building, independent from the choice of technical building systems and renewable energy systems.
- ISO 52018-1 provides an overview of options of indicators enabling (optional) specific EPB requirements (post-processing) at the level of the building as such (building energy needs or building fabric).

In addition, the Department for Communities and Local Government, UK [12] defines the energy rating of a building as a calculation which is based on a combination of factors:

- The type of building (i.e. flat, house or bungalow) and whether it is detached or not;
- The age of the building;
- The number of habitable rooms (excluding kitchens, bathroom hallways, stairs and landings);
- Extensions and their construction and rooms in the roof;
- The dimensions of the building and the number of floors;
- The amount and type of glazing (i.e. single or double glazing);
- The material used to build the property (e.g. brick, stone, timber frame, etc.);
- Wall insulation;
- Roof construction (e.g. flat, pitched) and insulation;
- The number of chimneys and open flues;
- The heating systems and the type of fuel used.

The energy rating is adjusted for the floor area of a building, so it is independent of size for a given type of building. The rating is calculated on the basis of standard occupancy to ensure that the results are consistent for similar building types and relate to the physical fabric of the building rather than the energy usage patterns of the individual occupant, which can vary appreciably between households. The rating is independent of the number of people living in the household, how many domestic appliances it has (such as washing machines and refrigerators) and how efficient they are and how residents choose to heat their home (i.e., individual temperature settings and how long it is heated during the day or night). However, when moving from the building scale to the neighborhood scale, additional energy consumption factors need to be considered. In this way, both in the aspects related to the assets of the urban space, as well as to the habits of operational use of the neighborhoods, it is necessary to identify new indicators that allow the evaluation of the energy performance of urban areas. Taking the list of 50 urban sustainability indicator frameworks analysed worldwide as a starting point, the following table presents a taxonomy showing 4 dimensions (environmental, economic, social and institutional), each with their respective thematic categories and indicators, specifying in each case the unit of measurement corresponding to each one (Table 3).

Table 3: Most frequent indicators of sustainability within the selected thematic categories.

Dimension	Thematic Categories	The Most Popular Indicators	*f* *
Environmental	Water	Domestic water consumption (litres/capita/day/year)	32
		Share of population connected to a public sewerage system and wastewater treatment system (%)	21
	Mobility and transport	Modal split—percentage distribution of average daily journeys: on foot, public transport, motorised private transport, and bicycles	26
		Motorisation rate—number of personal automobiles per capita	16
		Total length of bicycle lanes in km per 1000 inhabitants	12
	Waste	Municipal waste generated—in kg per capita	34
		Municipal waste recycling rate (%)	30
	Air quality	Annual mean concentrations of air pollutants: NO2, PM10, PM2.5 (μg/m3)	35
		Number of times that the limit of pollutants the NO2, PM10, O3 is exceeded	30
	Energy	Share of a city's total energy consumption that comes from renewable sources as a share of the city's total energy consumption (%)	28
		Total consumption of electricity in kWh per capita	21
	Land use	Shares of built-up area, forest, water, agricultural land, and other areas of the total city area (%)	30
		Share of protected nature areas of the total city area (%)	9
	Climate change	Total CO2 emissions (tCO2/capita/year)	36
Economic	Economy	City product per capita	21
		Number of businesses per 1000 inhabitants	12
	Employment	Unemployment rate (%)	26

		Employment percentage change since base year (%)	23
Social	Education	Early childhood education—children under six years of age who are enrolled in early childhood education programs (%)	11
	Health	Life expectancy at birth (male/female)	16
		Number of physicians and nursing personnel per 1000 inhabitants	13
	Housing	Housing costs—% of the total disposable household income	13
		Average living area per person (m2)	11
	Safety and security	Number of crimes reported annually per 1000 inhabitants	28
		Number of traffic accidents per year per 1000 inhabitants	14
	Equity (social, economic)	Income distribution (Gini Coefficient)	15
		Share of women and ethnic minorities in local government (%)	13
	Social infrastructure	Connection to services—percentage of households are connected to piped water, sewerage, electricity, gas distribution network, and broadband internet (%)	16
		Percentage of population living within 500 m of basic public services (%)	9
	Green space	Green area within the city (forests, parks, gardens, etc.) per inhabitant (m2/inhabitant)	26
		Percentage of inhabitants living within 300 m or 15 min walk from public green space > 5000 m2 (%)	10
	Culture	Public expenditure on culture per 1000 inhabitants	10
Institutional	Participation	Voter turnout—% of adult population who voted in the last municipal, presidential, national, and EU parliamentary elections	20
		Civic associations—number of voluntary non-profit organisations, including NGOs and political, sporting, or social organisations, registered or with premises in the city, per 1000 inhabitants	8

	Urban planning	Existence of documents for inciting sustainable and strategic urban development	7
	Environmental management	Number of enterprises and public and non-governmental organisations with certified Environmental Management Systems (IS014001/EMAS)	15
		Share of eco-labelled products in public procurement by city authorities	7
	Governance	Total debt per capita of a municipality (in euros)	15

f*: number of frameworks in which the indicator appears.

Source: Michalina, D., Mederly, P., Diefenbacher, H., & Held, B. (2021). Sustainable urban development: A review of urban sustainability indicator frameworks. Sustainability, 13(16), 9348.

The list of indicators in Table 3 does not differentiate between operational indicators and asset indicators. In the same way, many of the indicators that it presents are used to assess the sustainability and quality of life in neighborhoods, but they may or may not have an impact on energy consumption (as is the case of Total debt per capita of a municipality, Voter turnout —% of adult population who voted in the last municipal, presidential, national, and EU parliamentary elections, etc.)

The relationship between Sustainable Building Certification Systems and Energy Efficiency Certificates is that both aim to promote energy savings in the construction of buildings but focus on different aspects. While Green Building Certification Systems assess a wide range of assets and operational sustainable criteria (including energy efficiency as one indicator among many others), the Energy Efficiency Certificates focus specifically on the energy efficiency of the building, ruling out other element-related indicators that aim to sustainability. In some cases, green building certification schemes may require information from EPCs as part of their assessment process, as building energy efficiency is an important component of neighborhood sustainability.

3 Identifying Energy-Consuming Services on a Neighbourhood Scale

3.1 Objectives and Importance of Identifying Energy-Consuming Services

The importance of identifying "energy-consuming services" at the neighborhood scale lies in its potential to drive targeted and effective energy management strategies. By discerning the specific services and activities that contribute significantly to energy consumption, urban planners, policymakers, and communities can implement tailored energy efficiency measures. This knowledge enables the prioritization of resources and investments in areas with the most substantial impact, fostering sustainable development and reducing the neighborhood's overall energy footprint. Additionally, understanding energy-consuming services encourages community engagement and empowers residents to actively participate in energy conservation efforts, promoting a collective commitment to environmental sustainability and a greener, more resilient neighborhood.

The primary objectives of identifying "energy-consuming services" at the neighborhood scale are as follows:

1. Identifying and categorizing various energy-consuming services, to achieve a comprehensive assessment of the neighborhood's energy consumption patterns can be conducted. This enables a thorough understanding of the energy demands associated with different services and activities within the neighborhood.
2. Knowing the energy-consuming services will allows stakeholders and policymakers to target specific areas for energy efficiency improvements. This information can guide the implementation of tailored strategies to optimize energy consumption and reduce overall energy demand.
3. Understanding which services have the most substantial impact on energy consumption, to helps in making informed decisions regarding the design and layout of the neighborhood, aiming for energy-efficient infrastructure and buildings.
4. To explore opportunities for integrating renewable energy sources to meet specific energy demands. This integration can promote the use of clean and sustainable energy, contributing to the overall environmental sustainability of the neighborhood.

An in-deep analysis of the energy-consuming services at the neighborhood scale can make benefits in terms of a holistic energy management, in which understanding the full range of services that consume energy allows for an integral approach to energy management. This ensures that no sector is overlooked, and energy-saving measures can be implemented across various service areas. Also, it can promote an effective energy planning, through the collection of accurate data on energy-consuming services. This could help to identify potential areas of high energy consumption and highlights opportunities for optimizing energy usage.

In other hand, by targeting energy-consuming services, the neighborhood can reduce its carbon footprint and contribute to broader climate change mitigation efforts. The implementation of strategies to lower energy consumption could help to decrease greenhouse gas emissions, supporting global sustainability goals.

As a social consequence, identifying energy-consuming services can encourages community engagement and participation in energy-saving initiatives. Citizens become more aware of their energy use and are more likely to support and implement energy-efficient practices thanks to the community self-engagement.

Finally, implementing energy-saving measures based on identified energy-consuming services can lead to cost savings for residents and businesses. Lower energy consumption translates to reduced utility bills, benefiting the community economically.

3.2 Energy classification of energy consuming services at neighbourhood scale

The involvement of project partners in deliberations and exchanges helps to identify and classify the energy consuming services at neighbourhood scale. Moreover, the incorporation of measurement approaches for various indicators, encompassing both energy-related and non-energy-related aspects, added strength and validity to the proposed classification.

A table containing neighborhood-level energy consumption and sustainability indicators (where energy consumption indicators specifically pertain to energy use, and sustainability indicators provide a more holistic perspective, considering a wider range of factors that contribute to the long-term well-being) was presented to the partners, who were requested to rate their relevance on an urban scale using a scale ranging from "not related" to "somewhat related" to "highly related" (represented by 0, 0.5 and 1 respectively). The partners surveyed had technical and non-technical profiles. Finally, indicators with contradictory results were identified in the responses (that is, some responses classified them as "unrelated" and others as "highly related") and a determination of the final classification criterion for each indicator was sought in discussion meetings with the partners. This approach allowed for a thorough evaluation of the applicability of the indicators, ensuring a consensus-based classification that adequately reflects their importance in the context of neighborhood-scale evaluations. The obtained outcomes are presented in Table 4.

Table 4: Energy consuming services at neighbourhood scale.

DIMENSION	CATEGORY	ITEM	RELATED URBAN SERVICES						MANAGEMENT SECTOR
			Street Lighting	Urban Forests	Waste	Circulation infrastructure	Drinking Water	Sewers	
Building infrastructure	*Internal comfort*	*Individual assets ratings from buildings (Heating, cooling, ventilation, illumination, appliances, etc.)*	0	0	0	0	0,5	0	Mix
	Complex Buildings	*Common infrastructures*	0,5	0,5	0,5	0,5	0,5	0,5	Mix
Mobility (Distance in minutes by walk, using personal mobility, using public transport, using shared vehicles or using private vehicles)	*Education*	*Primary education*	0,5	0,5	0	1	0	0	Mix
		Secondary education	0,5	1	0	1	0	0	Mix
		Tertiary education	0,5	1	0	1	0	0	Mix
	Health services	*Primary care*	0,5	0,5	0	1	0	0	Mix
		Social Care	0,5	0,5	0	1	0	0	Mix
		Hospitals	0,5	0	0	1	0	0	Mix
	Social Activities	*Shopping*	0,5	0,5	0	1	0	0	Mix
		Entertainment	1	1	0	1	0	0	Mix
		Green zones	1	1	0	1	0	0	Mix
	Institutional services	*Banks*	0	0,5	0	1	0	0	Mix
		Public administration	0,5	0,5	0	1	0	0	Mix
Comfort	*Illumination*	Natural illumination	0	1	0	0	0	0	Mix
		Artificial illumination	1	1	0	0	0	0	Public

	Thermal loads	Insulation	0	0,5	0	0,5	0	0	Private
		Solar passive gains	0	1	0	0	0	0	Private
		Heat Island Effect	0,5	1	0	1	0	0	Private
		Sky View Factor	1	1	0	1	0	0	Private
		Natural based solutions	0	0	0	0	0	0	Private
	Air quality	External air quality	0	1	0,5	1	0	0,5	Public
		Internal air quality	0	0,5	0,5	1	0	0,5	Private
		Natural ventilation	0	0	0	0	0	0	
		Humidity	0	0,5	0	0,5	0	0	
		Allergens	0	1	0,5	0,5	0	0	
		Particles (PM)	0	1	0,5	1	0	0	
		CO2 and other	0	1	0,5	1	0	0	
	Noise	Internal noise	0	0,5	0	1	0	0	Private
		External noise	0	1	0	1	0	0	Public
	Health	Fungus	0	0,5	0,5	0	0	0,5	
		Ionizing radiation	0	0	0	0	0	0	
		Dangerous wildlife	0,5	1	0	0,5	0	0	
		Mental health	1	1	1	1	0	0	
		Other chemicals							
	Safety	Road	1	1	0	1	0	0	Public
		Criminality	1	0,5	0	0	0	0	Public
Land use	*Purpose*	*Generation capacity*	0	1	0,5	0,5	0,5	0	Mix
		Storage capacity	0	1	0,5	0,5	0,5	0	Mix
		Diversity of land uses	1	1	1	1	1	1	Mix
	Urban features	*Complexity of the urban fabric*	1	1	1	1	0,5	0,5	Mix
		Urban density (of the different land uses)	1	1	0,5	1	0,5	0,5	Mix
Accessibility to services	*Citizen services*	*Electricity*	1	0,5	0,5	0,5	1	0	Public
		Water	0	0	0	0	1	1	Public
		Waste	0	0	1	1	1	1	Public
		Illumination	1	0	0	0	0	0	Public
		Public transport	1	0	0	1	0	0	Public
	Community services	*Parking spaces*	1	0	0	1	0	0	Mix
	Civil services	*Security forces*	0,5	0,5	0	0,5	0	0	Public
		Telecommunications	0,5	0	0	0	0	0	Mix
	Energy	*Energy vectors (charging points / gas stations)*	0,5	0	0	1	0	0	Mix

Source: own elaboration

The services analyzed were six:

- Public Lighting: consists of the provision of artificial lighting in public areas at night. Its consumption is related to the area to be illuminated and the lighting levels required, among others.
- Urban Forests: consist of trees and green spaces within cities. Its consumption is related to the green area and the energy required for its maintenance.
- Waste: is the collection, elimination and management of various types of waste. Its consumption is related to the area of operation, population density and transportation, among others.
- Circulation infrastructure: includes roads and related systems that allow the movement of people and goods. Its consumption is related to the area, population density and type of transportation, among others.
- Drinking Water: delivery of clean and safe water for consumption and domestic use. Its consumption is related to the area, population density and household, commercial and industrial requirements, among others.
- Sewer: manage the collection and safe disposal of wastewater. Its consumption is related to the area, population density, among others.

It should be noted that the methodology used was based on the survey of the partners' criteria, and does not propose an inferential analysis of the factors by which each indicator is considered an energy consumer or not, for each service. In future analysis, understanding these relationships could be crucial for developing targeted energy efficiency strategies and neighbourhood sustainability interventions.

The analysis of the results revealed that, according to the criteria of the partners, services linked to Land Use and Service Accessibility indicators exhibit the strongest relationship with energy consumption. Specifically, indicators such as Diversity of Land Uses, Complexity of the Urban Fabric, and Urban Density, all dependent on the Land Use dimension, rise the highest consensus among the partners in terms of energy-consumption, with agreement percentages of 100%, 83.3%, and 75%, respectively. Subsequently, the Waste indicator achieved a 66.6% consensus, and Electricity garnered a 58.3% consensus among the partners, both falling under the category of Citizen Services. Additionally, it was found that indicators such as Common Infrastructures, Entertainment, Green Zones, Sky View Factor, External Air Quality, and Roads shared a 50% consensus as influential factors in neighborhood energy consumption.

The high level of consensus for certain indicators suggests a strong agreement among the partners regarding their significance in assessing energy consumption at the neighborhood scale. The focus on Land Use and Service Accessibility-related indicators indicates the relevance of urban planning and accessibility factors in determining energy demand patterns within neighborhoods. Furthermore, the identified indicators under Citizen Services highlight the impact of municipal services and utilities on energy consumption trends. Understanding these relationships is crucial for developing targeted energy efficiency strategies and sustainability interventions in neighborhoods.

It is important to note that some indicators reached only 50% consensus among partners. This shows a divergence of opinions among partners regarding the relevance of the indicator in energy consumption. This divergence emphasizes the need for further discussions and assessments to clarify the specific impacts of these indicators on neighborhood energy consumption and to arrive at a collective understanding of their importance. Overall, the analysis provides valuable insights into the selection and prioritization of indicators for neighborhood-scale energy consumption assessments, facilitating more informed decision-making and fostering sustainable urban development practices.

Regarding to the analysis of services, the strong correlation observed between the "Circulation infrastructure" and the "Street lighting" with the energy-consuming indicators suggests their significant impact on energy consumption within neighborhoods. Circulation infrastructure services, encompassing roads and transportation networks, plays a vital role in shaping commuting patterns and overall travel demand, thus influencing energy consumption as asset that conditioning the transportation needs. Similarly, street lighting, as a crucial component of urban infrastructure, directly affects energy usage in public lighting systems.

Urban forests also demonstrate a notable correlation with energy-consuming indicators. Their presence contributes to microclimate regulation, offering natural shading and cooling effects that can potentially reduce the energy demand for cooling in buildings, particularly during warm seasons. Furthermore, the provision of drinking water is intrinsically tied to the operation of water supply systems, which involves energy consumption for water treatment and distribution processes.

These results, obtained from the assessment that the partners made of the services based on their expertise, are shown in the Table 5.

Table 5: Classification of energy consuming services at neighbourhood scale.

Service	Energy Consumption Classification
Circulation Infrastructure	Highly Consuming
Street Lighting	Highly Consuming
Urban Forests	Moderately Consuming
Drinking Water Provision	Moderately Consuming
Sewers	Low Consuming
Waste Management	Low Consuming

Source: own elaboration

Once again, the analysis was based on the partners' criteria, so the table presents the results of the highest correlations observed in the responses, but does not seek to investigate which elements each partner considered to arrive at their assessment.

Circulation Infrastructure and Street Lighting are categorized as "Highly Consuming" services due to their robust correlation with energy-consuming indicators. Commensurate with this classification, circulation infrastructure, encompassing roads and transportation networks, exerts influence on commuting patterns and overall travel demand, thus significantly impacting energy consumption in transportation-related activities. Likewise, the provision of street lighting directly affects energy usage in public lighting systems.

For their part, according to the assessment expressed by the partners, Urban Forests and the Provision of Drinking Water are considered “Moderate Consumption” services. Urban forests contribute to the regulation of microclimates, potentially reducing the energy demand for cooling in buildings. Simultaneously, drinking water provision is intrinsically tied to energy consumption in water treatment and distribution processes.

Lastly, partners thought that Sewers and Waste Management should be assigned to the "Low Consuming" category, indicating their relatively minor impact on energy consumption. While these services are deemed indispensable, their energy requirements are not as substantial as those observed in the highly and moderately consuming services.

In addition, an extra column was added to the table to explore the question about the relationship between the analysed services and the final responsible of each one. Currently, through specific regulations in the real estate e-purchase-sale and rental market, it is sought that obtaining energy efficiency certificates for homes and buildings is a mandatory responsibility for private users and property owners. They are the ones who, bound by the rules imposed on the commercialization of real estate (purchase, sale and rental), request and hire consultancies or energy advisers to evaluate and certify the energy efficiency of their particular properties. However, the concept of energy efficiency label for neighborhoods implies a paradigm shift in which this responsibility is transferred to the public sector, in particular to the government at its different levels.

With the implementation of an energy efficiency label for neighborhoods, the public sector becomes a key stakeholder in ensuring the energy efficiency and sustainability of the built environment. The infrastructure of the urban space, public services, urban planning, urban transport, public trees, street lighting, the quality, type, and quantity of streets, routes, roads, and highways, urban facilities, or urban logistics among others, are all integral components that contribute to the energy performance of a neighborhood. These aspects fall under the jurisdiction and responsibility of the State or local authorities.

The public sector plays a crucial role in urban planning, infrastructure development, and the provision of public services. By taking an active role in promoting and implementing energy efficiency measures at the neighborhood level, the government can significantly impact the overall energy consumption and environmental footprint of an area.

This shift in responsibility towards the public sector is essential because it acknowledges that the energy performance of a neighborhood is not solely determined by individual buildings but is also influenced by the surrounding infrastructure and urban environment. It recognizes that the State has a vital role in creating sustainable, energy-efficient communities through effective urban planning, efficient public services, and the provision of adequate transportation options.

By implementing an energy efficiency label for neighborhoods, the public sector can prioritize and allocate resources towards energy-saving initiatives, renewable energy integration, and sustainable urban development. It enables the government to set energy efficiency goals, establish regulations and incentives, and collaborate with stakeholders to create holistic strategies for neighborhood-level energy efficiency improvements.

Ultimately, this shift in responsibility fosters a more comprehensive and integrated approach to energy efficiency, recognizing the interdependencies between buildings, infrastructure, and the urban environment. It promotes collaboration between the public and private sectors, encouraging a shared responsibility for achieving sustainable and energy-efficient neighborhoods.

Understanding the correlation between these services and energy-consuming indicators is essential for effective urban planning and energy management strategies. Policymakers and stakeholders can use this knowledge to identify key areas where energy efficiency measures can be targeted to optimize energy consumption in neighborhoods. Furthermore, knowing the impact of urban forests and drinking water services on energy demand can drive informed decision-making regarding the development of sustainable infrastructure, emphasizing the integration of green spaces and efficient water management systems. Overall, the analysis provides valuable insights into the interplay between services and energy consumption, aiding in the development of informed and comprehensive approaches for enhancing energy efficiency and promoting sustainability in urban neighborhoods.

4 Exploring Energy Communities and Smart Grids

4.1 Understanding Energy Communities and Smart Grids

The European Commission defines the Energy communities as open and voluntary and combine non-commercial aims with environmental and social community objectives. There are 3 directives which describes the key elements of two types of Energy Communities: Renewable Energy Communities and Citizen Energy communities. Under Citizen energy communities falls both the Gas and Electricity Market directive. Energy communities can be defined by ways, using the 'Citizen energy communities' [13] and taking the 'Renewable energy com*munities'* [14]. Both definitions have common elements:

- **GOVERNANCE :** "Participation must be open and voluntary" (renewable energy directive) "Households should find it easy to both enter & leave the energy community" (Electricity directive)
- **OWNERSHIP & CONTROL :** Both definitions emphasise participation and effective control by citizens, local authorities & smaller businesses whose **primary economic activity is not the energy sector!**
- **PURPOSE :** Their PRMARY purpose is to generate social & environmental benefits rather than focus on financial profits.
- **SIMILAR ACTIVITIES :** 'Citizen energy communities' & 'Renewable energy communities' can exercise similar activities:
    - Generation
    - Aggregation
    - Energy storage
    - Distribution
    - Consumption
    - Provision of energy related services
    - Supply
    - Sharing

The directives that give framework to Energy Communities are:

1 - Article 2(16) Recast Renewable Energy Directive[1]: stablish Renewable Energy Community as a legal entity:

(a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;

(b) the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities;

(c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits"

2 - Article 2(11) Recast Internal Electricity Market Directive[2]: defines Citizen Energy Community as a legal entity:

(a) based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises;

(b) has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits;

[1] eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021PC0802

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944

(c) may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders;"

3 - Article 2(70) Proposal Recast Internal Gas Market Directive[3], express that a Citizen Energy Community is a legal entity that:

(a) is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises;

(b) has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; and

(c) engages in production, distribution, supply, consumption, or storage of renewable gas in the natural gas system, or provides energy efficiency services or maintenance services to its members or shareholders;

Table 6: Citizen energy communities vs. renewable energy communities

Difference	CITIZEN ENERGY COMMUNITIES	RENEWABLE ENERGY COMMUNITIES
Geographical scope	Electricity directive **does not** bind energy communities to immediate vicinity.	Local communities **'must be in the vicinity'** of renewable energy projects owned/developed by that community.
Activities	Operate in electricity sector and are **technology-neutral** (fossil fuel source or renewable)	Broad range of activities related to all forms of renewable energy
Participants	**Any actor can participate,** but stakeholders involved in large-scalecommercial activity where energy is the primary economic activity cannot make decisions.	**Restricted Membership –** Natural persons, local authorities, MSMEs, who's membership/ participation is not their primary economic activity.
Autonomy	'Decision-making powers should be limited to those members or shareholders that are not engaged in large-scale commercial activity in the energy sector.'	'Capable of remaining autonomous from individual members or other traditional market actors that participate in the community as members or shareholders.'
Effective control	**Exclude Medium-sized and large enterprises** from being able to exercise effective control.	Can be controlled MSMEs that are **'located in the proximity'** of the renewable energy project.

Source: https://rural-energy-community-hub.ec.europa.eu/energy-communities/what-energy-community_en

In other hand, the advances of smart grids are one of the main trends in global energy development. The use of fundamentally new methods in energy and combining them into a holistic, interconnected, and independent infrastructure allows to maximize the capabilities of the energy system, implement the principle of distributed

[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0803

energy generation, increase the efficiency of load balancing in the network. In addition, the use of smart technologies in the power grid helps to better meet the needs of consumers.

For a comprehensive understanding of the state of the art and in-depth analysis of the peculiarities of the development of scientific research in the smart grids area, a bibliometric analysis carried out by Vakulenko [15] to study and determine the main scientific directions research area, was taken. Bibliometric analysis is an advanced tool for identifying existing "gaps" in the research topic, identifying areas of research that are most relevant and in line with current trends. Bibliometric analysis was performed according to the sequence shown in Table 7.

Table 7: Scientific research in the smart grids area

Stage	Filters	Result
Choice of suitable information sources	Scopus database	
Identification of search field in the database	Title, abstract, keywords	
Identification of search keywords	Smart grid	55015 publications
Identification of publication type	Journal articles only; conference papers, books, and chapters of books excluded	16037 publications
Choice of the language	English	14154 publications
Choice of the field of publication	Social Sciences, Business, Management and Accounting, Economics, Econometrics and Finance, Decision Sciences	1378 publications
Identification of the publications time limits	2008-2020 (since the beginning of the growth of the number of publications on the subject)	1359 publications
Manual check	The analysis of the paper in terms of its relevance	1 359 publications

Source: Vakulenko, I., Saher, L., Lyulyov, O., & Pimonenko, T.V. (2021). A systematic literature review of smart grids. E3S Web of Conferences.

Accordingly, the work chose for bibliometric analysis one of the most influential and authoritative scientific databases, Scopus. To study the topic, as a keyword was chosen "smart grid," this term is the main one and is officially used to describe the modernization of the energy sector based on intelligent technologies. Authors ensure the study's complexity and integrity, by using the search field "title, abstract, keywords". They selected 1359 publications for further consideration.

The dominance of technical publications, in particular, in the field of engineering, informatics, and energy was found. The highest citation rate – 2282 – was achieved in 2017. However, the largest number of citations per publication was in 2009 (81 citations per 1 publication). In 2009, two articles were published, ranking 1st and 3rd among the most cited, respectively. The period of active interest and strengthening of publishing activity in smart grids began in 2008. The highest citation rate – 2282 – was achieved in 2017. However, the largest number of citations per publication was in 2009 (81 citations per 1 publication). In 2009, two articles were published, ranking 1st and 3rd among the most cited, respectively.

Authors correlated the analysis of the number of publications and citations with trends in the development of smart grids. It allowed them to analyse the evolutionary development of research on smart grids. The basis for determining scientific interest was the number of published scientific papers on this topic. Public interest in the subject was determined based on Google Trends, which allowed to track the number of queries related to smart grids in the Google search engine. Its paper distinguishes four stages in the evolution of scientific and public interest in intelligent power grids:

a. The first stage fell in 2008-2009. This period is characterized by searching for ways to level technical and technological constraints for large-scale implementation of the first stage of smart grid development – forming a basis for full-fledged smart grid projects by deploying smart metering infrastructure. A small number of scientific papers characterizes this period. The shortage of scientific research, which considers the latest technical and technological advances in the development of smart grids, leads to a considerable increase in citations of existing scientific papers.
b. The second stage – 2009-2013 – is the transition from smart metering to the creation of full-featured smart grids. During this period, against the background of the concept's development for introducing smart grids in the energy sector by leading countries, researchers focus not on economic but on technical issues of smart grid configuration. The increase in the number of relevant scientific studies is accompanied by an almost twofold decrease in their citations of scientific papers. The results of the analysis in Google Trends show a significant increase in public interest in the topic of smart grids.
c. The third stage – 2014-2017 – is associated with the emergence of new technological constraints in developing smart grids. This period is characterized by a rapid increase in the number of scientific publications and their citation dynamics while reducing public interest in this issue.
d. Finally – from 2017 – is the search for breakthrough technologies that will determine the vector of development of smart grids in the future. During this period, it is worth noting the growing number of scientific papers. Simultaneously, there are multiple reductions of citations and also reduction of public interest in this issue due to unresolved technical and technological problems that do not increase smart grid projects` technical and economic efficiency. It is holding back investment in scaling up smart grids.

To identify existing research trends and identify current areas of further investigation, authors analysed the keywords of publications using VOSviewer, a reliable and effective tool to visualize the relationship between the main keywords in research. Three hundred seventeen keywords were selected for analysis (frequency of occurrence more than seven times), after checking the keywords for further consideration, repeated and irrelevant words (for example, "scheduling," "China," and others). A total of 280 keywords were analysed.

Table 8: Main Keywords linked with Smart Grid related concepts.

Concept	Main Keywords
Smart Grid	Energy Efficiency, Sustainability Energy, Alternative Energy, Electricity, Sustainable Development, Renewable Energy
Smart Power Grids	Electric Power Transmission Networks, Smart Grids, Network Security, Electric Power Distribution, Electric Power System Control, Smart Meters
Renewable Energy Resources	Electric Vehicles, Wind Power, Renewable Energy,
Optimization	Demand Response, Energy Management, Costs, Energy Utilization

Electric Utilities	Demand-Side Management, Energy Resources, Economics

Source: Own elaboration, using data input form Vakulenko, I., Saher, L., Lyulyov, O., & Pimonenko, T.V. (2021). A systematic literature review of smart grids. E3S Web of Conferences.

4.2 Assessment schemes for energy communities

Following Huang et.al. [16] the definition of Community Energy Planning (CEP) includes not only the community energy system and facility design but also all energy-related issues in a community, such as a setting energy consumption target, selecting energy resources, and energy conversion technologies evaluation.

The authors indicate that the original definition of community is a social group of any size whose members reside in a specific locality. They, instead, refer to its geographic meaning and consider community as a unit of the city, which means a small-scale area with mixed land use (preferably less than 10 km^2, but not limited to such areas). The region is divided by streets and roads into more than two blocks. The most important feature is that all the objects belong to one urban detailed planning project, which means all objects can be comprehensively considered and operated by planners. Most urban development projects and new town constructions correspond with the above features. Compared with traditional primary energy planning (PEP), it is possible regard CEP as secondary energy planning, as the operating object of CEP is secondary energy (the energy can be used directly, such as hot water, chilled water, electricity and household fuels). Concerning the time logic, CEP comes after PEP. Traditional PEP is "supply-side" energy planning, whereas CEP is "demand-side" energy planning. The differences between CEP and traditional PEP are listed in Figure 1.

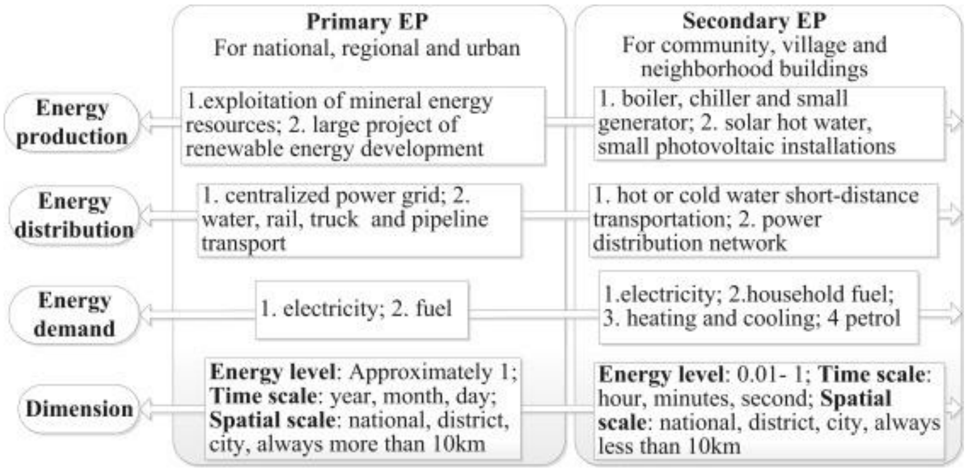

Figure 1: Differences between Community energy planning and traditional Primary energy planning

Source: Zishuo Huang, Hang Yu, Zhenwei Peng, Mei Zhao, Methods and tools for community energy planning: A review.

The main contents of CEP at different stages of a community development project are rich. The tasks of CEP at the community master planning stage, community detailed plan stage and architectural design stage are illustrated by Figure 2.

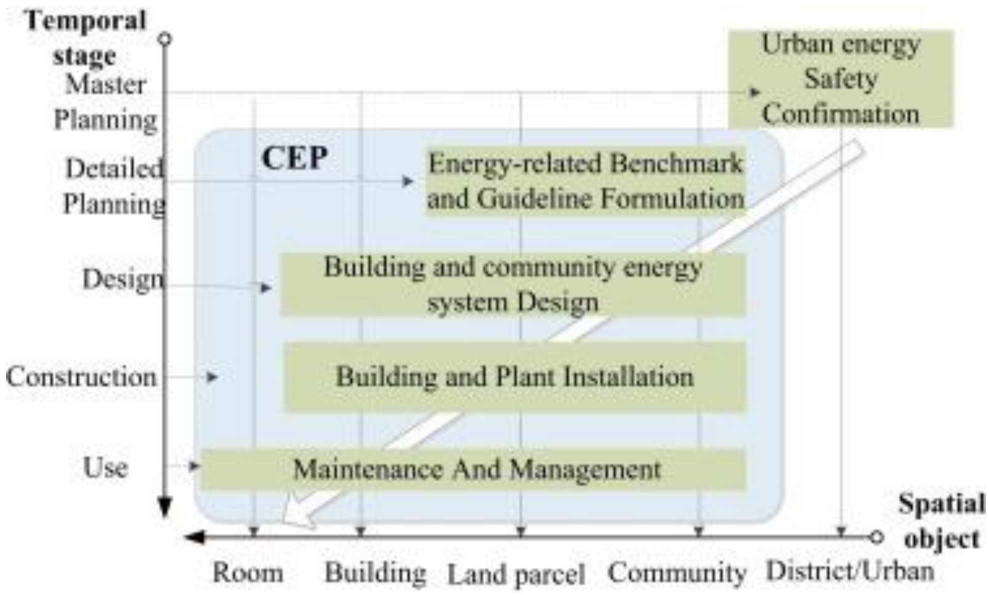

Figure 2: Main task of Community energy planning at different stage

Source: Zishuo Huang, Hang Yu, Zhenwei Peng, Mei Zhao, Methods and tools for community energy planning: A review.

In Stage 1, known as the Community Master Plan (CMP), community goals and aspirations for future development are established. The outcome of this stage results in public policy and development principles encompassing various aspects, including transportation, utilities, land use, recreation, and housing. CMPs typically cover large geographical areas, address a wide range of topics, and extend over long timeframes. The CMP process involves identifying issues, setting goals, collecting data, preparing the plan, creating implementation strategies, evaluating alternatives, adopting the plan, implementing it, and monitoring progress.

Energy planning within the CMP stage serves several key purposes:

1. Confirming energy demand and planning significant energy facilities.

2. Adjusting the relationships between the energy department and other departments, as well as the internal energy system departments, considering factors like growth, scale, and the structure of different energy types.

3. Managing costs and controlling investments for energy projects.

4. Establishing guidelines for formulating energy policies.

In Stage 2, referred to as the Community Detailed Plan (CDP), the planning is based on the CMP and involves setting specific control indicators for land use and other management requirements. It also includes making detailed arrangements for facility construction and building design. The CDP stage comprises the Community Regulatory Plan (CRP) and Community Site Plan (CSP).

During the CRP stage, energy planning focuses on defining energy-related goals for the community and land parcels. In the CSP stage, Comprehensive Energy Planning (CEP) involves infrastructure planning for energy systems, such as municipal heating networks, heating stations, power distribution networks, and fuel gas networks. The primary planning principle here is ensuring a balance between energy supply and demand, without considering the interconversion of different energy sources on the demand side.

Finally, in Stage 3, known as Architectural Design (AD), building energy system design is integrated with architectural appearance and structural design. Energy engineers in this stage are primarily responsible for creating a comfortable indoor environment through the design of heating, ventilation, and air conditioning (HVAC) systems, as well as strategies for lighting and noise control.

Overall, these stages represent a structured approach to urban and community development, where energy planning plays a crucial role in ensuring sustainable and efficient energy use throughout the planning and construction processes.

The core problem of energy planning is to resolve the contradiction between the current supply and current demand, as well as current supply and future demand, which are involved in energy security issues. Because of the oil crisis during the 1970s, many governments realized the need to reduce reliance on oil. Thus, laws about municipal facility plans (MP) were created and implemented. At present, integrated renewable and non-renewable energy resource planning (IRP) and demand-side management (DSM) have replaced the earlier MP, which focused only on the arrangement of primary energy sources (coal, oil and fuel gas).

Focusing on the CMP and CRP stages, it is found that energy planning is usually based on energy policy. It is evident that Comprehensive Energy Planning (CEP) is implemented through a top-down model. This top-down model employs overarching policies to drive the adoption of energy-saving measures. Energy policies can be categorized as Planning Guidance, Rating System, Indicator System, and National or Local Standard System. These standards and guidance documents are formulated based on accumulated experience from numerous projects and statistical data. Within a top-down framework, planners reference information from other communities or cities to establish guidelines and corresponding measures for their planning area. Consequently, this model can be characterized as an "exogenous" approach.

in this framework, tools like BREEAM Communities and LEED-ND are extensively employed for the design and assessment of low-carbon eco-communities in many countries. In the context of a community energy system, the LEED-ND rating system places considerable emphasis on achieving specific energy consumption targets. It incentivizes engineers to design high-performance buildings and employ rational energy technologies to attain these energy objectives. BREEAM Communities, on the other hand, is tailored to the conditions of the UK, accounting for project-specific factors like geographic location and climate while also highlighting the tangible effects of technologies. Both systems impose relatively stringent requirements on the energy systems of low-carbon eco-communities. However, for large and densely populated urban areas, adhering to these criteria can be challenging.

Without systematic and effective methodologies for analyzing community energy systems during the detailed urban planning stage, establishing energy consumption goals and proposing practical recommendations for subsequent designers and property owners becomes problematic. To conduct a comprehensive analysis of community energy systems, it is imperative to undertake a systematic evaluation of these systems.

While the BREEAM Community and LEED-ND rating systems incorporate certain energy-related indices for assessing community energy utilization, their suitability relies on the similarity of energy demand characteristics and renewable energy resource conditions among communities. Applying these rating systems mechanically across all communities is unsuitable as they fail to account for variations in energy resources and demands among different communities.

On the other hand, bottom-up models are routinely employed for Comprehensive Energy Planning (CEP) during the Community Site Plan (CSP) and Architectural Design (AD) stages. This type of models encompasses both simulation and dynamic energy system optimization components. It enables the acquisition of CEP programs through technical analysis of the community energy system.

The framework of bottom-up models for CEP comprises three primary modules: community energy demanding, available energy resource, and energy conversion technologies. These modules are interconnected via the first and second laws of thermodynamics and additionally incorporate economic and environmental constraints.

Energy demand within an urban area encompasses cooling, heating, electricity, and fuel load, categorized into building, industrial, and transportation energy consumption. Industrial and transportation energy consumption relies on factors like industrial output and traffic volume, while building energy consumption is influenced by population, construction area, building performance, and resident habits, making its precise prediction challenging. Methods for building energy demand forecasting include statistical regression, time series forecasting, and key factor forecasting.

Additionally, building energy simulation is employed for short-term, hour-by-hour thermal/cold demand prediction and building energy system analysis. It calculates building load based on user inputs and internal libraries, considering factors like weather, solar conditions, schedules, lighting, equipment, heat transfer, and ventilation. Some frequently used building performance simulation tools are DOE-2 (eQUEST) developed by the Lawrence Berkeley National Laboratory, EnergyPlus (American Department of Energy and Lawrence Berkeley National Laboratory), ESP-r, by the Department of Mechanical Engineering University of Strathclyde, TRNSYS bye the University of Wisconsin Madison, and Dest developed by the Tsinghua University.

Other models to use are based on the load indexes are derived from energy consumption data of existing buildings, allowing for the calculation of energy consumption in the planning area based on land use planning, and in the energy Resource Assessment evaluates the capacity of energy resources, particularly renewable and sustainable ones, considering environmental and economic aspects. Available models for assessing renewable energy resources include theoretical potential, available capacity, and economic acceptable capacity calculations.

It is worth mentioning that the energy supply system optimization, is viewed as a constraint optimization problem, where the goal is to optimize energy production, distribution, and utilization while adhering to investment, energy resource, and energy demand constraints. Various mathematical methods such as Linear Programming (LP) and Non-Linear Programming (NLP) are employed, often complemented by approximation algorithms. Advanced techniques like Simulated Annealing (SA), Genetic Algorithms (GA), Tabu Search (TS), Evolution Strategies (ES), Artificial Neural Networks (ANN), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO) are used to tackle distribution systems planning and optimization challenges.

Computer tools for Comprehensive Energy System Design (CESD) encompass various software applications and models designed to facilitate the planning, analysis, and optimization of energy systems at different scales. Several notable tools in this domain include EnergyPLAN, E-GIS, SUNtool, and others.

EnergyPLAN is a computer tool that enables hour-by-hour simulation of regional or national energy systems, covering aspects such as electricity, heating, cooling, industry, and transportation. It is developed by Aalborg University, Denmark, and is focused on sustainable energy system design using both renewable and fossil energy sources. The tool serves the purpose of aiding in the design of energy planning strategies at the national and local levels.

E-GIS, or Environment and energy Geographical Information System, is a tool that facilitates integrated energy demand forecasts and energy system optimization for urban areas. It involves the creation of an E-GIS Database that combines urban GIS data, urban planning information, environmental data, and energy consumption data. This integrated approach allows urban planners to make informed decisions related to city planning, environmental considerations, and energy management.

SUNtool (Sustainable Urban Neighborhood modeling tool) is designed for early decision-making in sustainable urban design. It optimizes building layouts, microclimate design, and sustainable energy plans for neighborhoods, considering factors like heating, cooling, and electricity loads. SUNtool employs building envelope heat balance equations and resident occupant stochastic models to calculate energy demands, with a focus on urban microclimates, human behavior, and resource management.

Other computer tools and models for CESD are also available, such as HOMER, DER-CAM, EAM, MARKAL/TIMES, RETScreen, and H2RES. These tools contribute to the design of future community energy systems. Additionally, there are multi-energy models for simulating and optimizing urban energy infrastructure planning, mixed-integer programming (MILP) models for decentralized energy generation systems, and models and tools for various stages of long-term model-based energy planning processes.

Overall, these computer tools play a crucial role in urban and regional energy system planning, helping planners and decision-makers assess design options, policies, and technologies to address the complex challenges of urban energy systems.

Community Energy Planning (CEP) methods vary across different stages of community construction. During the Community Master Plan (CMP) and Community Regulatory Plan (CRP) stages, standards and rating systems like LEED-ND and BREEAM Communities are widely used for low-carbon community development. These systems provide energy-related indicators that guide energy system design and equipment installation. This top-down approach aligns with existing urban planning processes and is commonly adopted in community development projects.

However, sometimes these rating systems may not perfectly fit a project's needs, requiring the involvement of a specialized team comprising urban planners and energy experts. In contrast, during the Community Site Plan (CSP) and Architectural Design (AD) stages, community energy system analysis and simulation models such as RETScreen, H2ERS, EnergyPlan, DER-CAM, and EAM are commonly employed. These tools assist engineers and property owners in designing distribution and renewable energy systems, selecting energy-efficient technologies, and meeting heating, cooling, and electricity demands effectively and efficiently.

Recent research has largely focused on methods for predicting community energy demand, evaluating available energy resources, and optimizing energy system structures. Computer tools for building energy simulation play a crucial role in predicting community energy demand, using methods like statistical regression and load index. Regarding Computer tools for Comprehensive Energy System Design (CESD), a comparison of various optimization models reveals their primary focus on optimizing community energy production and distribution. However, most models do not predict energy demand or evaluate energy resources, except for SUNtool and E-GIS, which feature integrated energy simulation modules.

At the comprehensive planning stage, technical models like LEAP and MARKAL are used for national and large-scale area energy plans, while RETScreen, though capable of community energy planning, is primarily focused on renewable and clean energy projects. These models typically require users to input energy demand and available energy resource information, and the models, integrated with optimization algorithms and energy conversion technologies databases, provide optimization solutions. It is emphasized that energy demand should be accurately classified based on its specific use, and a general classification of energy demand is illustrated for data input in models like DER-CAM, RETScreen, and H2RES.

5 Defining Criteria for Neighbourhood Classification

5.1 Objectives of Classification Criteria

In pursuit of the goal to develop a new energy performance evaluation scheme at the neighborhood scale, the initial step involved establishing the criteria to define the urban area under assessment. Extensive analysis and discussions were conducted with relevant stakeholders to explore various options and reach a consensus. The agreed criteria for defining the evaluation area entails the designation of a closed polygon, collaboratively determined by the payer and the technical evaluator. This polygon is carefully constructed to ensure it is devoid of any internal holes or overlaps. The boundaries of this polygon will be demarcated by significant elements that can include infrastructure, geographical features, political or administrative divisions, among others.

The significant elements considered for delineating the evaluation area comprise a wide range of factors. These can encompass common service infrastructure like transportation networks or utility systems, community installations of renewable energies, natural elements such as rivers, mountains, and forests, political or administrative borders such us postal codes, or energy communities, among others. Figures 3 - 6 shows right and wrong area delimitation taking as an example an area of government buildings intended for administrative use.

By incorporating these elements into the evaluation area, the methodology ensures a comprehensive and context-specific assessment of energy performance at the neighborhood scale. It acknowledges the influence of various relevant factors on energy consumption and sustainability within the defined boundaries. This approach could facilitate a more accurate understanding of the energy dynamics and enables targeted interventions and improvements to enhance the overall energy performance of the neighborhood.

Figure 3: Right assessment polygonal area delimitation

The Figure 3 shows the delimited polygonal area for government buildings intended for administrative use.

Figure 4: Wrong assessment polygonal area delimitation. Holes.

In the case of the example in the Figure 4, the delimited polygonal area shows an internal hole.

Figure 5: Wrong assessment polygonal area delimitation. Random perimeter.

In the case of the example in Figure 5, the polygonal area was defined without considering the significant elements of the urban fabric. As a consequence, one of its edges crosses an area in a random way.

Figure 6: Wrong assessment polygonal area delimitation. Non continuous perimeter.

Figure 6 shows the polygonal area defined without holes and following significant elements of the urban fabric, but this time it is a non-continuous geometric figure. In any case, independent assessments could be requested for each delimited area, but in no way could it be considered a single evaluation for separate areas.

5.2 Determination of Reference Values

To establish an urban area for evaluation when issuing an energy performance certificate at the neighborhood scale, the payer and the technical evaluator must follow a methodological set of systematic and collaborative steps to define an assessment area. The key steps involved are:

- Collaborative Discussions: The payer and the technical evaluator should engage in collaborative discussions to understand the objectives, requirements, and limits of the evaluation. This step allows for alignment and agreement on the purpose and scope of the energy performance certificate.
- Identification of Stakeholders: Identify and involve relevant stakeholders who have a vested interest in the evaluation area. This may include local authorities, community representatives, architects, urban planners, and energy experts. Their input is valuable in defining the boundaries and assessing the energy performance of the neighborhood.
- Consideration of Relevant Factors: Assess various factors that influence the energy performance of the neighborhood. These factors can include infrastructure, geographical features, political or administrative divisions, and other elements mentioned in the previous text (e.g., common service infrastructure, community installations of renewable energies, rivers, mountains, forests, borders, postal codes, energy communities). This may involve considering the proximity, connectivity, or other specific criteria. Determine which factors are most relevant to the asset energy performance assessment.
- 4Roadmap: The payer and the technical evaluator must collaborate to develop a clear and comprehensive step by step roadmap for defining the evaluation area. This serves as a guide for determining the boundaries of the neighborhood to be assessed. It should include the follow key considerations:
    - *Factors and Criteria:* Identify the relevant factors that could influence the choice of a neighborhood area. This can include infrastructure, geographical features, political or administrative divisions, and other significant elements mentioned earlier. Define specific criteria for each factor to determine its inclusion or exclusion in the evaluation area.

  - *Data Availability and Accessibility:* Assess the availability and accessibility of data related to the identified factors. Consider data sources such as maps, official records, community databases, or stakeholder input. Ensure that the chosen factors can be supported by reliable and up-to-date information to ensure the accuracy of the evaluation.
  - *Consistency and Replicability:* Look for that the defined criteria and approach can be consistently applied to different neighborhoods or future evaluations. This will allow for comparability and scalability of the evaluation process.
  - *Stakeholder Engagement:* Involve relevant stakeholders in the roadmap establishment process. Seek input from local authorities, community representatives, urban planners, and experts in energy efficiency. Incorporate their perspectives and expertise to enhance the methodology's effectiveness and relevance.
  - *Documentation and Communication:* Document the developed roadmap in a clear and accessible format. Describe the rationale behind the selected factors and criteria and provide guidance on how to apply the successive steps. Communicate the roadmap to all involved parties, ensuring a shared understanding of the approach.
- <u>Consensus Building:</u> Reach a consensus between the payer and the technical evaluator on the methodology developed. This step involves addressing any conflicting perspectives and finding common ground for defining the evaluation area.
- <u>Boundary Definition:</u> Once the methodology for evaluating the neighbourhood's energy performance is established, the payer and the technical evaluator can proceed with defining the boundaries of the evaluation area. Here are the key steps involved in the boundary definition process:
  - *Identification of Significant Elements:* Identify the significant elements mentioned in the methodology that will be used to delimit the boundaries. These elements can include infrastructure, geographical features, political or administrative divisions, and other relevant factors. Make sure there is a clear understanding of how each element contributes to the boundary definition.
  - *Data Gathering:* Collect the necessary data and information related to the identified significant elements. This may involve accessing maps, geographical data, administrative records, or other sources that provide information about the selected elements. Ensure the accuracy and reliability of the data to support the boundary definition process. The use of Geographic Information System (GIS) technologies and other related tools to aid in the boundary definition process are recommended.
    - Data Integration: Integrate the collected data related to the significant elements into a GIS platform. This can involve importing various data layers, such as infrastructure maps, land use data, administrative boundaries, and geographical features. Ensure that the data is properly organized and compatible with the GIS software.
    - Spatial Analysis: Utilize GIS tools to perform spatial analysis on the integrated data. This can include overlaying different layers to identify areas of overlap or proximity to specific elements. Conduct spatial queries and calculations to derive meaningful insights that contribute to the boundary definition.
    - Visualization and Mapping: Leverage GIS technologies to visually represent the identified significant elements and their spatial relationships. Generate maps that display the selected elements, existing infrastructure, and other relevant features. Use color coding, symbology, and labeling to enhance the visualization of the evaluation area boundaries.
    - Geospatial Decision Support: Employ geospatial decision support systems or other related technologies to aid in the decision-making process. These tools can provide analytical capabilities and scenario modelling to assess different boundary options. Use the outputs of these tools to inform the collaborative discussions and reach a consensus on the final boundary definition.
    - Documentation and Reporting: Document the use of GIS technologies and related tools in the boundary definition process. Include information about the specific software, methodologies, and analyses employed. Document any limitations or considerations related to the use of these technologies. This documentation serves as a record of the spatial analysis conducted and enhances the transparency and reproducibility of the boundary definition.

- Documentation and Agreement: Document the agreed-upon boundaries and methodology in a formal agreement or contract. Ensure that all parties involved, including the payer, the technical evaluator, and relevant stakeholders, review and approve the documentation.

By following these criteria, the payer and the technical evaluator can collaboratively establish an urban area for evaluation when issuing an energy performance certificate at the neighborhood scale. This process ensures transparency, consensus, and a well-defined assessment area for accurate energy performance evaluation.

5.3 Corrections and Adaptations for Energy Consumption Classification

The so-called asset rating is the calculation of the energy performance of buildings, using an asset rating methodology based on simulated or modelled energy consumption results, considering physical characteristics of the building such as its envelope characteristics and air leakage, combined with reported measurements from equipment manufacturers [17]. This standardised method of measuring and comparing the energy performance potential of buildings is widely adopted across the EU, with the 14 Member States (MSs) utilizing it as the main procedure for issuing EPC, while 11 MSs apply a combination of calculated and measured rating. The methodology of asset rating assesses the primary energy needs without addressing losses during energy production. Next, a list of asset indicators linked to energy performance is proposed for the evaluation of neighbourhoods.

According to EN ISO 52000-1:2017, the measured energy indicator and the measured energy performance is the energy performance indicator based on measured energy performance and the energy performance based on weighted measured amounts of delivered and exported energy respectively. The measured energy performance, also known as operational energy performance, is the weighted sum of all energy carriers used by the building, as measured by meters or derived from measured energy by other means. It is a measure of the in-use performance of the building after correction or extrapolation. This is particularly relevant to certification of actual energy performance. Operational performance is only applicable to existing buildings in the use phase. Buildings energy operational indicators are essential for measuring and evaluating the energy performance of buildings, which is critical for achieving energy efficiency and sustainability goals. By tracking these indicators, building owners and managers can identify areas where energy efficiency improvements can be made, which can reduce energy consumption, lower operating costs, and mitigate the environmental impact of building operations.

Energy consumption indicators (ECI) are one of the most common and straightforward indicators used to measure building energy performance. They can measure the total energy used by a building, a specific system, or individual equipment. ECI can provide valuable insights into overall energy usage trends, which can help building owners and managers identify opportunities for reducing energy consumption and optimizing energy use. It can also deliver information related to the efficiency of building components such as heating and cooling systems, lighting, and insulation, among others. By measuring the energy efficiency of these components, building owners and managers can identify areas where upgrades or replacements may be necessary to improve overall energy efficiency and reduce energy consumption. Greenhouse gas emissions indicators are also critical for measuring the environmental impact of building operations. These indicators can track emissions from building operations, including energy consumption, transportation, and waste management. By measuring greenhouse gas emissions, building owners and managers can identify opportunities for reducing emissions and mitigating the environmental impact of building operations.

Finally, renewable energy production indicators can assess the contribution of renewable energy sources to a building's energy mix. These indicators can help building owners and managers determine the feasibility of implementing renewable energy technologies, such as solar or wind power, to meet their energy needs.

Below, a preliminary taxonomy of indicators is presented for the evaluation of the energy consumption of assets at the neighbourhood scale. It consists of three dimensions: Environmental, Social and Institutional. Within these dimensions, a total of 6 categories and 23 indicators were identified. The relevance and weighting factor of the indicators were the subject of open discussion with the partners. Its inclusion was analyzed based on its usefulness to evaluate various energetic and non-energetic parameters. By encompassing multiple dimensions and a wide range of indicators, the taxonomy presented in Table 9 is expected to enable a comprehensive assessment of energy consumption performance at the neighbourhood level.

The discussion and collaboration with partners ensured that the selected indicators are meaningful and applicable to the context of neighborhood-scale assessments. Furthermore, the consideration of measurement methodologies for both energy-related and non-energy-related parameters enhances the robustness of the proposed taxonomy.

Table 9: Taxonomy of Asset Energy Consumption Indicators at the neighborhood scale

Dimension	Cathegory	Indicator	Proximity	Energy	Social	LCA	LCC
Enviromental	Neighbourhood Services	Urban Conditioning (District heating and cooling)	% of population covered by the district heating/cooling	Annual energy intensity of heating/cooling (kWh/(km2 · hab))	Thermal confort	Annual emissions intensity of heating/cooling (tCO2e/(km2 · hab))	Annual costs of urban heating/cooling (EUR/(km2 · hab))
		Hot Water	% of population reached by renewable and efficient Domestic and Urban DHW systems	Annual energy intensity of HW (kWh/(km2 · hab))	Thermal confort	Annual emissions intensity of DHW (tCO2e/(km2 · hab))	Annual costs of urban DHW (EUR/(km2 · hab))
		Illumination	% of population with access to street lighting with more than Eh 20 lux	Annual energy consumed by the street lighting and lighting urban assets (kWh/(km2 · hab))	Security, Accesibility, Visual Comfort and Stetic	Annual emissions produced by the street lighting and lighting urban assets (tCO2e/(km2 · hab))	Annual costs produced by the street lighting (EUR/(km2 · hab))
		Water distribution	% of population reached by water distribution systems	Annual energy consumption to provide the water consumption (kWh/(km2 · hab))	Water Poverty Index Water Quality Index	Annual emissions produced to provide the water consumption (tCO2e/(km2 · hab))	Annual costs produced to provide the water consumption (EUR/(km2 · hab))
		Sewage	% of population covered by a water treatment plant	Annual energy intensity of the water treatment plants (kWh/(km2 · hab))	% of population connected to a water treatment plant Ecological Risk Index	Annual emissions intensity of the water treatment plants (tCO2e/(km2 · hab))	Annual costs of the water treatment plants (EUR/(km2 · hab))
		Service Station (fuels)	% of population with access to a service	Annual energy consumption (excluding the energy serviced	Charging Infrastructure Index	Annual emissions of the service station / EV	Annual costs (excluding the cost of the energy vector

			station / EV charging point of in less than 1% of standard fuel tank (diesel, gas, CNG, LNG, H2) / battery.	to the vehicles) of the service station / EV charging point (kWh/(km2 · hab))		charging point (tCO2e/(km2 · hab))	serviced to the vehicles) of the service station / EV charging point (tCO2e/(km2 · hab))
		Electricity distribution	% of population reached by renewable and efficient electrical systems	Annual electricity consumtion intensity (kWh/(km2 · hab))	Annual percentage of hours of electricity provision Global infrastructure index (GINF)	Annual emissions produced by electricity consumtion (tCO2e/(km2 · hab))	Annual costs of electricity consumtion (EUR/(km2 · hab))
		Telecommunication services	% of population covered by 5G	Annual energy consumption by the telecommunication system (kWh/(km2 · hab))	Annual percentage of hours of service provision Telecommunication Infrastructure Index	Annual emissions produced by the telecommunication system (tCO2e/(km2 · hab))	Annual costs produced by the telecommunication system (EUR/(km2 · hab))
		Solid waste management	% of population covered by separate waste collection systems	Annual energy consumption by the waste collection system (kWh/(km2 · hab))	Ecological Risk Index	Annual emissions produced by the waste collection system (tCO2e/(km2 · hab))	Annual costs produced by the waste collection system (EUR/(km2 · hab))
	Urban Comfort	Heat Island	% of population affected by the excess of temperature	Annual of excess or defect energy intensity of heating/cooling due to the process of a heating island (kWh/(km2 · hab))	Intensity of Urban Heat Island (ºC)	Annual of excess or defect emissions produced due to the heating island (tCO2e/(km2 · hab))	Annual cost for excess or defect energy intensity of heating/cooling due to the process of a heating island (EUR/(km2 · hab))
		Air quality	% of population affected by low air quality index	Annual energy intensity of ventilation (kWh/(km2 · hab))	Year Average Common Air Quality Index Moran Index (MI)	Annual emissions intensity produced by ventilation (tCO2e/(km2 · hab))	Annual costs produced by ventilation (EUR/(km2 · hab))
		Noise	% of population affected by high noise levels	Annual energy intensity of noise insulation (kWh/(km2 · hab))	Year averange common City Noise-Air index	Annual emissions intensity of noise insulation systems	Costs of noise insulation systems (EUR/(km2 · hab))

						(tCO2e/(km2 · hab))	
	Energy	Energy Generation	% of population with access to local renewable energy generation services	Annual maximum energy generation intensity (kWh/(km2 · hab))	Self consumption (%) Thail Index Power Quality Index	Annual maximum emissions produced by the generation intensity (tCO2e/(km2 · hab))	Annual maximum costs produced by the generation (EUR/(km2 · hab))
		Energy Storage	% of population with access to energy storage / local balancing services	Annual maximum energy cumulative intensity (kWh/(km2 · hab))	Autarky rate (%) Thail Index Power Quality Index	Annual maximum emissions produced by the cumulative intensity (tCO2e/(km2 · hab))	Annual maximum costs produced by the cumulative (EUR/(km2 · hab))
Social	Urban mobility	Public Transport	% of population with 500m of a public transport stop	Annual energy consumption of the public transport used (kWh/(km2 · hab))	Transport sustainability index Walkability Index	Annual emissions of public transport needs of the population (tCO2e/(km2 · hab))	Annual costs produced by the public transport needs of the population (EUR/(km2 · hab))
		Private Transport	% of population with 500m of a public or private car park	Annual energy consumption of the private transport needs (kWh/(km2 · hab))	Precense of Low Emission Zone in the district	Annual emissions of transport needs (tCO2e/(km2 · hab))	Annual costs produced by the transport needs (EUR/(km2 · hab))
		Accessibility	% of population withing 500m of distant to different point of interest in the urban area	Average energy consumption (kWh) taken by the population to reach to specific places	15-Minute City Index Walkability index	Average emissions produced (tCO2e) taken by the population to reach to specific places	Average costs produced (EUR) taken by the population to reach to specific places
	Economics	Logistics	% of population withing 500m of distant to a logistic drop point or to a loading and unloading yards	Annual energy consumption of logistic services in the neighbourhood (kWh/(km2 · hab))	MSCI Circular Economy Index	Annual emissions produced by logistic services (tCO2e/(km2 · hab))	Annual costs produced by logistic services in the neighbourhood (EUR/(km2 · hab))
		Burden of Poverty	% of population affected by households that cannot carried out the recommendati	Annual energy consumption of not carry out the recomendations set in the SmartLivingEPC	Health impact of not carry out the recomendations set in the	Annual emissions of not carry out the recomendations set in the SmartLivingEP	Annual costs of not carry out the recomendations set in the SmartLivingEP

			ons set in the SmartLivingEPC	(kWh/(km2 · hab))	SmartLiving EPC (DALYs)	C (tCO2e/(km2 · hab))	C (EUR/(km2 · hab))
		Real-life conditions	% of population within the AROPE rate	Consumption of buildings and urban areas, associated with socio-demographic variables (kWh/(km2 · hab))	AROPE indicator (At risk of poverty and/or exclusion)	Emissions produced associated with socio-demographic variables (tCO2e/(km2 · hab))	Costs produced, associated with socio - demographic and quality of life variables (EUR/(km2 · hab))
Institutional	Urban Plannig	Urban Density	% of population on zones with 50000 hab/km2	Solar heat gains/energy savings (kWh/(km2 · hab))	Human density index (HDI) Population density index (PDI)	Annual emissions saved by the use of solar heat gains (tCO2e/(km2 · hab))	Annual costs saved by the use of solar heat gains (EUR/(km2 · hab))
	Green Areas	Urban green spaces / forests	% of population with access to green spaces and urban forest	Annual energy consumption required to keep the urban green space / forest (kWh/(km2 · hab))	Vegetation index Normalized Difference Vegetation Index (NDVI)	Annual emissions to manage the urban green space / forest (tCO2e/(km2 · hab))	Annual costs to manage urban green spaces / forest (EUR/(km2 · hab))
		Urban agriculture	% of population with access to places for urban agriculture	Annual energy consumption used to manage the urban agriculture space (kWh/(km2 · hab))	Vegetation index Normalized Difference Vegetation Index (NDVI)	Annual emissions produced to manage the urban agriculture space (tCO2e/(km2 · hab))	Annual costs produced to manage urban agreiculture space (EUR/(km2 · hab))

Source: Own elaboration

The table under consideration consists of a total of six columns. The initial three columns work together to form a hierarchical taxonomy organized into three distinct scales: dimension, category, and indicator. These scales provide a systematic framework for categorizing and understanding the various elements presented in the table.

Moving forward, the subsequent columns delve into the conceptual definitions of each indicator, considering three distinctive analytical perspectives: Proximity, Energy, and Social. These three perspectives offer a multi-faceted view of how each indicator can be interpreted and assessed within the given context.

The Proximity perspective considers the indicator in terms of its spatial relationships and how closely related it is to other factors. This lens emphasizes the geographical aspect of the indicators and how they interact within their physical proximity. For each indicator, this column provides a conceptual definition in qualitative terms.

Shifting to the Energy perspective, we explore how each indicator relates to the energy aspects of the context it addresses. This analysis helps in understanding the energy implications of the indicator, both in terms of consumption and potential energy-related impacts. Like the Proximity perspective, the Energy viewpoint offers a conceptual definition and outlines the unit of measurement for each indicator.

Finally, the Social perspective considers the implications of the indicator for social dynamics and relationships within the context. It delves into how the indicator can influence or be influenced by social factors, offering a broader understanding of its social relevance. Note that the definitions in this column are supported by current

relevant indices. However, at this stage of work progress the most appropriate index for each has not yet been defined. For this reason, tentatively, there are cells in which you will find more than one index.
It is highlighted that a critical step in the next stages will be the definition of the ways in which these indicators will be evaluated within the framework of the project, determining aspects such as specific formulas, data sources and the participation of the component tools proposed by SmartLivingEPC. The taxonomy presented is a work in progress, in which the focus has been primarily on conceptualizing and categorizing these indicators as a fundamental step in the process. As we move forward, our next stage will encompass the development of precise evaluation methodologies, including the formulation of mathematical procedures. These methodologies will consider data sources and the integration of relevant components, addressing the specific characteristics of each indicator.

The characterization of eight indicators from the table in Chapter 5 is presented below as an example. To facilitate comprehension, a standardized template was developed. This template includes the Indicator Name, Definition, and Calculation Procedure for five different aspects: Proximity, Energy, Social, Life Cycle Analysis (LCA), and Life Cycle Costing (LCC). The selected indicators are aligned with specific assets at the neighborhood scale.

Table 10: Characterization of Burden of Poverty Indicator

Category	**Economics: This category focuses on evaluating the overall urban services aspects of a neighborhood, which includes Logistics, Burden of Poverty and Real-life conditions**	
Indicator name:	**Burden of Poverty**	
Proximity (%)	This measures the percentage of the total population directly and indirectly affected by households that cannot carried out the recommendations set in the SmartLivingEPC	**Calculation Procedure**: Identify the buildings whose annual salary if the inhabitants is X% of the total investment cost reflected in the individual SmartLivingEPC recomendations. Divide this by the total amount of inhabitants of the neighbourhood and multiply by 100.
Energy (kWh/(km2 · hab))	This measures the amount of energy wasted by not carried out the recommendations set in the SmartLivingEPC.	**Calculation Procedure:** Identify the households that cannot affort (do not have savings, do not have access to fundings) the cost reflected in the individual SmartLivingEPC recomendations. Sum the energy savings indicated on the individual SmartLivingEPC recommendations for those buildings and normilize by neighbourhood area and the total number of inhabitants.
Social (Score)	This measure the impact of the health of the population of not carry out the recomendations set in the SmartLivingEPC (DALYs)	**Calculation Procedure:** Identify the households that cannot affort (do not have savings, do not have access to fundings) the cost reflected in the individual SmartLivingEPC recomendations. Identify the improvement of the IAQ and excess temperature in summer and defect temperatures in winter indicated on the individual SmartLivingEPC recommendations for those buildings and then follow the methodology stated in [4,5 and 6]to stimate the number of DALYs losed.
Life Cycle Analysis (tCO2e/(km2 · hab))	This indicator evaluates the environmental impacts associated with all stages of the life cycle of the households that cannot carried out the recommendations set in the SmartLivingEPC, factored by both area and population, within the urban area.	Calculation procedure: Make an inventory of households that cannot afford the cost reflected in the individual SmartLivingEPC recommendations (that do not have savings or access to financing). Evaluate the total emissions in tCO2 of the life cycle of the homes (Te). Calculate what the amount of emissions in tCO2 from the life cycle of the homes would be if they could implement the recommendations (Ter). Obtain the value of the Cost of Inaction using Te - Ter. Finally, divide them by the product of the urban area (in square kilometers) and the population (inhabitants).
Life Cycle Costing (EUR/(km2 · hab))	This indicator evaluates the cost associated with all stages of the life cycle of the households that cannot carried out the recommendations set in the SmartLivingEPC, factored by both area and population, within the urban area.	Calculation procedure: Make an inventory of households that cannot afford the cost reflected in the individual SmartLivingEPC recommendations (that do not have savings or access to financing). Evaluate the total costs of the life cycle of the homes (Tc). Calculate what the life cycle cost of the homes would be in EUR if they could implement the recommendations (Tcr). Obtain the value of the Cost of Inaction using Tc - Tcr. Finally, divide them by the product of the urban area (in square kilometers) and the population (inhabitants).

[4] https://www.sciencedirect.com/science/article/pii/S0033350623003359

[5] https://www.tandfonline.com/doi/full/10.1080/14733315.2023.2198800

[6] https://academic.oup.com/ije/article/52/3/783/6893949

Table 11: Characterization of Accessibility indicator

Category	**Urban Mobility: This category focuses on evaluating the overall urban services aspects of a neighborhood, which includes Public Transport, Private Transport and Accesibility**
Indicator name:	**Accessibility**
Proximity (%)	This indicator measures the percentaje of population withing X meters of distant to different point of interest in the urban area.
	Calculation Procedure: This is a multivalue indicator (one indicator per point of interest). Identify the point of interests inside the neighbourhood. Calculate the area of influence of each point of interest as a circle of center the point of interest and radious X meters. Next, identify the buildings that are inside the area of influence of each point of interest. Finally, sum all the inhabitants of those buildings and and normilize by neighbourhood area and total number of inhabitants.
Energy (kWh/(km2 · hab))	This indicator measures energy used by the population to reach different point of interest in the urban area.
	Calculation Procedure: This is a multivalue indicator (one indicator per point of interest). Identify the point of interests inside the neighbourhood. Calculate the fuel cost for the inhabitants of each building to reach the nearest point of interest. Next, estimate the amount of times a person visit this point of interest in the year and multiply these two quantities by the number of people that live in the building. Finally, sum all the energy consumtions of all the buildings and normilize by neighbourhood area and total number of inhabitants.
Social (Score)	This indicator measures the time used by the population to reach different point of interest in the urban area.
	Calculation Procedure: This is a multivalue indicator (one indicator per point of interest). Identify the point of interests inside the neighbourhood. Calculate the distance that each buildings has to the nearest point of interest (per type) and transform it to time dividing by 4.5 km/h. Finally, calculate the median value all the times.
Life Cycle Analysis (tCO2e/(km2 · hab))	This indicator evaluates the Life cycle emissions produced by the population to reach to specific places (Recreational and cultural spaces, Educational, Health, Shopping, Public administration, Financial infrastructure), factored by both area and population, within the urban area.
	Calculation Procedure: Calculate the maximum distance at which a vehicle can reach the point of interest emmiting less than 150 grCO2e. Next, identify the buildings of interest that are within the distance that can be traveled emitting less than 150 grCO2e. Finally, add all the inhabitants of those buildings and normalize by neighborhood area and total number of inhabitants.
Life Cycle Costing (EUR/(km2 · hab))	This indicator evaluates the life cycle costs produced by the population to reach to specific places (Recreational and cultural spaces, Educational, Health, Shopping, Public administration, Financial infrastructure), factored by both area and population, within the urban area.
	Calculation Procedure: Calculate the maximum distance that a vehicle can travel spending less than 1% of the cost of a full tank of fuel, or 1% of the charge of a battery. Next, identify buildings of interest that are within travelable distance spending less than 1% of the cost of a full tank of fuel or 1% of the charge of a battery. Finally, add all the inhabitants of those buildings and normalize by neighborhood area and total number of inhabitants.

Table 12: Characterization of Air Quality Indicator

Category	**Urban Comfort: This category focuses on evaluating the overall urban services aspects of a neighborhood, which includes Heat Island, Air quality and Noise**
Indicator name:	**Air Quality**
Proximity (%)	This indicator measures the percentage of the population affected by low air quality, indicating the extent of the population exposed to poor air conditions.
	Calculation Procedure: Count all the inhabitants of the neighborhood. Identify the population exposed to low air quality within the analyzed area. Calculate the percentage of affected neighbors with respect to the total number of residents in the neighborhood.
Energy (kWh/(km2 · hab))	This evaluates the annual energy intensity related with ventilation assets, measured in kWh per unit area and per capita within the urban area.
	Calculation Procedure: Determine the total energy used for ventilation in the urban area (in kWh), and divide it by the product of the urban area (in square kilometers) and the population (inhabitants). The result is the annual energy intensity for ventilation in kWh per square kilometer per inhabitant.
Social (Score)	Measures the impact on the quality of life and health of residents living in areas affected by low air quality levels
	Calculation Procedure: Identify the incidence of respiratory and dermatological diseases. Assign scores or values to each parameter based on established criteria or standards. Combine these values to get an overall score. A higher score generally indicates greater negative social impact within the neighborhood.
Life Cycle Analysis (tCO2e/(km2 · hab))	This indicator evaluates the environmental impacts associated with all stages of the life cycle of the ventilation asset, factored by both area and population, within the urban area.
	Calculation procedure: Identify the assets related to ventilation and the impacts to be evaluated. Collect data on all inputs and outputs of the ventilation systems throughout its life cycle. Evaluate the life cycle emissions of the ventilation system within the urban area and divide them by the product of the urban area (in square kilometers) and the population (inhabitants).
Life Cycle Costing (EUR/(km2 · hab))	This indicator evaluates the costs associated with all stages of the cost cycle of the ventilation asset, factored by both area and population, within the urban area.
	Calculation procedure: Identify the assets related to ventilation and their costs to be evaluated. Collect data on all inputs and outputs of the systems throughout its cost cycle. Evaluate the life cycle costing of the ventilation system within the urban area and divide them by the product of the urban area (in square kilometers) and the population (inhabitants).

Table 13: Characterization of Heat Island Indicator

Category	**Urban Comfort: This category focuses on evaluating the overall urban services aspects of a neighborhood, which includes Heat Island, Air quality and Noise**	
Indicator name:	**Heat Island**	
Proximity (%)	This indicator measures the percentage of the population affected by the excess of temperature due to the urban heat island effect.	Calculation Procedure: Count all the inhabitants of the neighborhood. Identify the population affected by the urban heat island effect within the analyzed area. Calculate the percentage of affected neighbors with respect to the total number of residents in the neighborhood.
Energy (kWh/(km2 · hab))	This evaluates the annual excess or defect energy intensity of heating/cooling due to the urban heat island process, measured in kWh per unit area and per capita within the urban area.	Calculation procedure: Determine the annual energy intensity of buildings in the neighborhood from consumption data in kWh. Calculate through simulation the application of systems to maintain the interior temperature of buildings in a range of 21ºC to 24ºC and a relative humidity of between 30% and 50%. Finally, calculate the difference of the Energy used with mitigation measures - Energy used without mitigation measures, and divide this result by the product of the total neighborhood area in square kilometers (Km2) and the total number of neighborhood residents.
Social (Score)	Measures the impact on the quality of life and health of residents living in areas affected by high temperatures caused by the urban heat island effect.	Calculation Procedure: Identify values of frequency and severity of extreme heat episodes, incidence of respiratory, cardiovascular and cerebrovascular diseases and mortality from heat-related diseases. Assign scores or values to each parameter based on established criteria or standards. Combine these values to get an overall score. A higher score generally indicates greater negative social impact within the neighborhood.
Life Cycle Analysis (tCO2e/(km2 · hab))	This considers the annual excess or defect emissions produced by the heating/cooling due to the urban heat island effect, measured in tCO2e per unit area and per capita within the urban area.	Calculation procedure: Determine the intensity of CO2 emissions of the buildings in the neighborhood based on the life cycle analysis, in tCO2e. Simulate the application of systems to maintain the interior temperature of buildings in a range of 21ºC to 24ºC and a relative humidity between 30% and 50% and calculate emissions during the life cycle of the buildings. Finally, calculate the difference between emissions with mitigation measures - emissions without mitigation measures, and divide this result by the product of the total area of the neighborhood in square kilometers (Km2) and the total number of residents of the neighborhood.
Life Cycle Costing (EUR/(km2 · hab))	This considers the annual excess or defect costs produced by the heating/cooling due to the urban heat island effect, measured in EUR per unit area and per capita within the urban area.	Calculation procedure: Determine thecost of the buildings in the neighborhood based on the life cycle analysis, in EUR. Simulate the application of systems to maintain the interior temperature of buildings in a range of 21ºC to 24ºC and a relative humidity between 30% and 50% and calculate emissions during the life cycle costing of the buildings. Finally, calculate the difference between costs with mitigation measures - costs without mitigation measures, and divide this result by the product of the total area of the

	neighborhood in square kilometers (Km2) and the total number of residents of the neighborhood.

Table 14: Characterization of Service Station (Fuels) Indicator

Category	**Neighbourhood Services: This category focuses on evaluating the overall urban services aspects of a neighborhood, which includes Urban Conditioning, Illumination, Water distribution, Sewage, Electricity distribution, Solid waste management and others service-related systems.**
Indicator name:	**Service Station (Fuels)**
Proximity (%)	This indicator measures the percentage of the population with access to a service station (of the different fuel types, including standard fuels an EV charging point) within a short distance.
	Calculation Procedure: Calculate the area of influence of a service station considering it as the maximum distance at which a vehicle can reach the service station without using more than 1% of the fuel standar tank. Next, identify the buildings that are inside the area of influence of the service station. Finally, sum all the inhabitants of those buildings and and normilize by neighbourhood area and total number of inhabitants.
Energy (kWh/(km2 · hab))	This evaluates the annual energy consumption (excluding the energy serviced to the vehicles) of the service station or EV charging point, considering both per-unit area and per-capita energy consumption.
	Calculation Procedure: Determine the total energy consumed by the service station or EV charging point within the urban area in kWh (excluding the energy provided to the vehicles). Then divide it by the product of the urban area (in square kilometers) and the population (inhabitants).
Social (Score)	Measures the impact on the quality of life of residents who lives in the radius of influence of a service station or charging point.
	Calculation Procedure: Identify IAQ values, environmental noise, intrusive light, road safety. Assign scores or values to each parameter based on established criteria or standards. Combine these values to get an overall score. A higher score generally indicates a higher negative social impact within the neighborhood.
Life Cycle Analysis (tCO2e/(km2 · hab))	This considers the annual emissions of the service station or EV charging point (excluding emissions from the energy serviced to vehicles) within the urban area, accounting for both per-unit area and per-capita emissions.
	Calculation procedure: Identify the assets related to service station and EV charging point and their impact to be evaluated. Collect data on all inputs and outputs of the system throughout its life cycle. Evaluate the life cycle emissions of each service station or EV charging point in tCO2e and add them. Divide the result by the product of the urban area (in square kilometers) and the population (inhabitants).
Life Cycle Costing (EUR/(km2 · hab))	It evaluates the annual costs (excluding the cost of the energy vector serviced to the vehicles) of the service station or EV charging point, considering both area and population factors, within the urban area.
	Calculation procedure: Identify the assets related to service station and EV charging point and the costs to be evaluated. Collect data on all inputs and outputs of the system throughout its life cycle costing. Evaluate the life cycle costing of each service station or EV charging point in EUR and add them. Divide the result by the product of the urban area (in square kilometers) and the population (inhabitants).

Table 15: Characterization of Urban Conditioning Indicator

Category	**Neighbourhood Services: This category focuses on evaluating the overall urban services aspects of a neighborhood, which includes Urban Conditioning, Illumination, Water distribution, Sewage, Electricity distribution, Solid waste management and others service-related systems.**
Indicator name:	**Urban Conditioning (District Heating and Cooling)**
Proximity (%)	Urban conditioning measures the percentage of the population within the urban area that is covered by urban heating and cooling systems. Evaluate the accessibility of these systems for residents.
	Calculation Procedure: Measure the total land area of the neighborhood in square kilometers (Km2). Next, identify and calculate the land area reached by urban conditionig services (including streets, equipped public transport stops, among others). Divide the total land area of urban thermal conditionig services by the total land area of the neighborhood and multiply the result by 100 to get the percentage.
Energy (kWh/(km2 · hab))	This indicator measures the annual energy intensity of heating and cooling within the neighborhood, expressed in kilowatt-hours per square kilometer per resident (kWh/(km2 · inhab)). Provides information on the efficiency of the neighborhood's urban environmental conditioning system.
	Calculation Procedure: Determine the total energy intensity in one year by the neighborhood climate service in kilowatt-hours (kWh). Then, divide this energy intensity by the product of the total neighborhood area in square kilometers (Km2) and the total number of neighborhood residents. The result is the annual energy intensity for urban environmental conditioning in kWh per square kilometer per inhabitant.
Social (Score)	Evaluates the number of days of the year in which temperatures approach historical maximums and minimums. It indicates the need for environmental conditioning of the neighborhood to achieve recommended values of thermal comfort for residents.
	Calculation Procedure: Calculate parameters related to thermal comfort, such as air temperature, wind speed, solar radiation or thermal sensation, among others. Assign scores or values to each parameter based on established criteria or standards. Combine these scores or values to obtain an overall environmental comfort index. A higher index score generally indicates a more comfortable environment within the neighborhood.
Life Cycle Analysis (tCO2e/(km2 · hab))	This indicator evaluates the environmental impacts associated with all stages of the life cycle of the district heating and cooling asset, factored by both area and population, within the urban area.
	Calculation procedure: Identify the assets related to the urban thermal conditioning service and their impact to be evaluated. Collect data on all inputs and outputs of the system throughout its life cycle. Evaluate the life cycle emissions of the heating and cooling system within the urban area and divide them by the product of the urban area (in square kilometers) and the population (inhabitants).
Life Cycle Costing (EUR/(km2 · hab))	This indicator evaluates the costs associated with all stages of the cost cycle of the district heating and cooling asset, factored by both area and population, within the urban area.
	Calculation procedure: Identify the assets related to the urban thermal conditioning service and their costs to be evaluated. Collect data on all inputs and outputs of the system throughout its cost cycle. Evaluate the life cycle costing of the heating and cooling system within the urban area and divide them by the product of the urban area (in square kilometers) and the population (inhabitants).

Table 16: Characterization of Sewage Indicator

Category	**Neighbourhood Services: This category focuses on evaluating the overall urban services aspects of a neighborhood, which includes Urban Conditioning, Illumination, Water distribution, Sewage, Electricity distribution, Solid waste management and others service-related systems.**
Indicator name:	**Sewage**
Proximity (%)	This measures the percentage of the population covered by a water treatment plant, indicating access to sewage treatment services.
	Calculation Procedure: Measure the total land area of the neighborhood in square kilometers (Km2). Next, identify and calculate the land area connected to a water treatment plant. Divide the total land area of sewage services by the total land area of the neighborhood and multiply the result by 100 to get the percentage.
Energy (kWh/(km2 · hab))	This indicator evaluates the annual energy intensity of the water treatment plants within the neighborhood, considering both the per-unit area and per-capita energy consumption. Provides information on the efficiency of the neighborhood's segawe system.
	Calculation Procedure: Determine the total energy consumed by water treatment plants within the urban area in kilowatt-hours (kWh). Then, and divide it by the product of the urban area (in square kilometers) and the population (inhabitants). The result is the annual energy intensity for the sewage network, expressed in (kWh/(km2 · hab)).
Social (Score)	Measures the impact on the quality of life of residents who live within the radius of influence of a water treatment plant, or who are deprived of sewage service.
	Calculation Procedure: Identify the presence or absence of a water treatment plant (WTP) within the neighborhood. Calculate the distance each building has from the WTP. Define an area of influence of 500m around the water treatment plant. Identify the buildings that are within the radius of influence. Identify the incidence of gastrointestinal, respiratory and dermatological diseases among the inhabitants of buildings inside the area of influece. Assign scores or values to each parameter based on established criteria or standards. Combine these values to get an overall score. A higher score generally indicates greater negative social impact within the neighborhood. Calculation Procedure: Identify the presence or absence of sewer network. Identify the incidence of gastrointestinal, respiratory and dermatological diseases among inhabitants of buildings that do not have access to sewage network. Assign scores or values to each parameter based on established criteria or standards. Combine these values to get an overall score. A higher score generally indicates greater negative social impact within the neighborhood.
Life Cycle Analysis (tCO2e/(km2 · hab))	This considers the emissions intensity of water treatment plants and the sewage network at all stages of the life cycle, accounting for both emissions per unit area and per capita, within the urban area.
	Calculation procedure: Take an inventory of the assets related to the water treatment plants and sewage network within the area of the neighbourhood and identify the impacts to be evaluated. Collect data on all inputs and outputs of the system throughout its life cycle. Evaluate the life cycle emissions of the water treatment plants and sewages in tCO2, and divide them by the product of the urban area (in square kilometers) and the population (inhabitants).
Life Cycle Costing (EUR/(km2 · hab))	It evaluates the total costs associated with water treatment plants and sewages system, considering both area and population factors, within the urban area.

	Calculation procedure: Identify the assets related to the water treatment plants and sewage network within the urban area and the impacts to be evaluated. Collect data on all inputs and outputs of the system throughout its life cycle. Evaluate the life cycle costing of the water treatment plants and sewage net in EUR, and divide them by the product of the urban area (in square kilometers) and the population (inhabitants).

Table 17: Characterization of Illumination Indicator

Category	**Neighbourhood Services: This category focuses on evaluating the overall urban services aspects of a neighborhood, which includes Urban Conditioning, Illumination, Water distribution, Sewage, Electricity distribution, Solid waste management and others service-related systems.**
Indicator name:	**Illumination**
Proximity (%)	This indicator measures the percentage of the population with access to street lighting providing more than 20 lux of illumination. It assesses the availability of adequate street lighting for the residents.
	Calculation Procedure: Measure the total land area of the neighborhood in square kilometers (Km2). Next, identify and calculate the land area reached by urban street lighting services (including lighting of the roads, traffic lights, luminous ads, among others). Divide the total land area of street lighting services by the total land area of the neighborhood and multiply the result by 100 to get the percentage.
Energy (kWh/(km2 · hab))	This indicator evaluates the annual energy intensity related to street lighting and lighting urban assets within the neighborhood, expressed in kWh/(km2 · inhab). Provides information on the efficiency of the neighborhood's street lighting network.
	Calculation Procedure: Determine the total energy intensity in one year by the neighborhood urban lighting service in kilowatt-hours (kWh). Next, divide this energy intensity by the product of the total neighborhood area in square kilometers (Km2) and the total number of neighborhood residents. The result is the annual energy intensity for urban environmental conditioning in kWh per square kilometer per inhabitant.
Social (Score)	This indicator assesses various factors related to street lighting such as Security, Accesibility, Visual Comfort and Stetic. These aspects focus on the overall lighting environment's impact on the residents' quality of life.
	Calculation Procedure: Calculate street lightnig parameters related to Security (driving), Accesibility (people with visual disabilities), Visual Confort (related with specific tasks or activities) and Stetic (integration of public lighting into the urban landscape). Assign scores or values to each parameter based on established criteria or standards. Combine these scores or values to obtain an overall street lighting index. A higher index score generally indicates a more lighting and visual comfort environment within the neighborhood.
Life Cycle Analysis (tCO2e/(km2 · hab))	This indicator considers the environmental impacts produced in all stages of the life cycle of the street lighting and lighting urban assets, factored by both area and population, within the urban area.
	Calculation procedure: Identify the assets related to the street lighting and lighting urban assets within the urban area and the impacts to be evaluated. Collect data on all inputs and outputs of the system throughout its life cycle. Evaluate the life cycle emissions of the street lighting and lighting urban assets in tCO2, and divide them by the product of the urban area (in square kilometers) and the population (inhabitants).
Life Cycle Costing (EUR/(km2 · hab))	It assesses the costs associated with street lighting and lighting urban assets, factored by both area and population, within the urban area.

	Calculation Procedure: Calculate the costs of the life of the street lighting and lighting urban assets within the urban area in EUR, and divide it by the product of the urban area (in square kilometers) and the population (inhabitants).

6 Conclusions

The deliverable laid the foundation for the development of an asset methodology for building complex scale. A comprehensive analysis of the existing assessment schemes was carried out, with a particular focus on urban sustainability frameworks and neighborhood sustainability assessment tools. The findings reveal that urban sustainability frameworks are organized into three dimensions: environmental, economic, and social, with an additional institutional dimension. However, it was observed that the institutional dimension of sustainability was inadequately represented. The neighborhood sustainability assessment tools also demonstrated an underrepresentation of the social and institutional dimensions. Furthermore, significant progress was made in the identification and classification of energy-consuming services at the neighborhood scale. The analysis indicated that infrastructure for circulation and street lighting, followed by urban forests and drinking water provision, were the most prominent energy-consuming services.

The deliverable explored and analyzed the most advanced discussions surrounding the concepts of Energy Communities, Smart Grids, and Building Units' Interaction. This comprehensive analysis contributed to the foundational understanding of these concepts. Building upon this work, collaborative discussions were held with project partners to determine the most appropriate criteria for delimiting the energy performance evaluation areas. This determination is one of the basis for issuing energy efficiency certificates at the neighborhood level, ensuring accurate and effective evaluation. Future work for the development of energy efficiency certificates at the neighborhood level includes the validation of the indicators detected through the implementation of surveys according to the Delphi method.

References

[1]. Michalina, D., Mederly, P., Diefenbaher, H., & Held, B. (2021). Sustainable Urban Development: a review of Urban Susutainability Indicator Frameworks. Sustainability 2021, 13, 9348.

[2]. Sharifi, A., Dawodu, A., & Cheshmehzangi, A. (2021). Neighborhood sustainability assessment tools: A review of success factors. Journal of Cleaner Production, 293, 125912.

[3]. Dang, X., Zhang, Y., Feng, W., Zhou, N., Wang, Y., Meng, C., Ginsberg, M., 2020. Comparative study of city-level sustainability assessment standards in China and the United States. Journal of Cleaner Production 251, 119622

[4]. Siew, R.Y.J., 2018. Green Township Index: Malaysia's sustainable township rating tool. Proc. Inst. Civ. Eng.Eng. Sustain. 171(4), 169-177

[5]. European Parliament and Council Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union, L 153, 18 June 2010, pp. 13-35.

[6]. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

[7]. ISO 52000-1 https://epb.center/support/documents/iso-52000-1/

[8]. ISO 52003-1 https://epb.center/support/documents/iso-52003-1/

[9]. ISO 52010-1 https://epb.center/support/documents/iso-52010-1/

[10]. ISO 52016-1 https://epb.center/support/documents/iso-52016-1/

[11]. ISO 52018-1 https://epb.center/support/documents/iso-52018-1/

[12]. Department for Communities and Local Government, UK (2017), A Guide To Energy Performance Certificates For The Marketing, Sale And Let Of Dwellings; ISBN: 978-1-4098-4216-3, online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671018/A_guide_to_energy_performance_certificates_for_the_marketing__sale_and_let_of_dwellings.pdf, accessed May 2023

[13]. Directive (EU) 2019/944 - (Electricity cover)

[14]. Directive (EU) 2018/2001 – (Renewable energy cover)

[15]. Vakulenko, I., Saher, L., Lyulyov, O., & Pimonenko, T.V. (2021). A systematic literature review of smart grids. E3S Web of Conferences.

[16]. Zishuo Huang, Hang Yu, Zhenwei Peng, Mei Zhao, Methods and tools for community energy planning: A review, Renewable and Sustainable Energy Reviews, Volume 42, 2015, Pages 1335-1348, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2014.11.042.

Goldstein , D.B., Eley, C. A classification of building energy performance indices. Energy Efficiency 7, 353–375 (2014). https://doi.org/10.1007/s12053-013-9248-0

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