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Review

Energy Storage in Urban Areas: The Role of Energy Storage Facilities, a Review

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Abstract: Positive Energy Districts can be defined as connected urban areas, or energy-efficient and flexible buildings, which emit zero greenhouse gases and manage surpluses of renewable energy production. Energy storage is crucial for providing flexibility and supporting renewable energy integration into the energy system. It can balance centralized and distributed energy generation, while contributing to energy security. Energy storage can respond to supplement demand, provide flexible generation, and complement grid development. Photovoltaics and wind turbines together with solar thermal systems and biomass are widely used to generate electricity and heating, respectively, coupled with energy system storage facilities for electricity (i.e., batteries) or heat storage using latent or sensible heat. Energy storage technologies are crucial in modern grids and able to avoid peak charges by ensuring the reliability and efficiency of energy supply, while supporting a growing transition to nondepletable power sources. This work aims to broaden the scientific and practical understanding of energy storage in urban areas in order to explore the flexibility potential in adopting feasible solutions at district scale where exploiting the space and resource-saving systems. The main objective is to present and critically discuss the available options for energy storage that can be used in urban areas to collect and distribute stored energy. The concerns regarding the installation and use of Energy Storage Systems are analyzed by referring to regulations, and technical and environmental requirements, as part of broader distribution systems, or as separate parts. Electricity, heat energy, and hydrogen are the most favorable types of storage. However, most of them need new regulations, technological improvement, and dissemination of knowledge to all people with the aim of better understanding the benefits provided.

Keywords: PED; energy transition; energy storage; electricity; heat; chemical energy

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1. Introduction

Energy transition has been set as the main global strategy towards the climate neutrality and energy security targets, and different efforts at the international level are demonstrating how integrating climate change adaptation and mitigation actions can support urban areas' holistic transformation by ensuring sustainable development.

Positive Energy Districts have become one of the emerging concepts in addressing the energy transition of European cities where the aim of implementing 100 PED by 2025 according to the Strategic Energy Technology Plan is being pursued by the growing research in defining them as a group of connected districts, urban areas, or energy-efficient and flexible buildings that emit zero greenhouse gases and manage surpluses of annual active renewable energy production [1].

The concept of PED is attracting and growing attention because of its self-supply of energy from Renewable Energy Sources (RES) towards the decarbonization of buildings, infrastructures, and systems as the main climate change mitigation strategy in urban areas [2]. The generated energy can be used immediately or stored for later use. The type of storage depends on the type of generated or converted energy (heat, electricity, etc.). The suitable types for energy storage always depend on the storage period. This can be a short-term or a long-term period of storage [3]. Some applications can be used for a short-term period of storage, mostly for a few days. These applications can be used in bad weather conditions when energy generation is minimized or there is no any energy generation, by ensuring continuous energy supply during energy demand peaks. Otherwise, long-term storage is aimed at offering available energy sources for more extended periods when renewable energy sources do not supply enough energy for the required energy demand. Summer time energy storage for the winter period is such a case.

Energy storage technologies play a key role in supporting a growing transition toward nondepletable power sources. Fossil fuels have been the primary source of energy, but they are finite and harmful to the environment [4–6]. This has stimulated the development of renewable energy technologies [7]. However, the energy produced by these resources tends to be intermittent and therefore relies on storage systems to provide a reliable power supply [8].

Furthermore, a constant increase in power demand due to population growth and the desire for rural electrification also causes variability in energy production [9]. Therefore, integrating energy storage systems (ESSs) into modern energy grids strengthens the system's resilience, making renewable energy more accessible and smart grids more effective and reliable [8,10]. The purpose of a storage system is to bring power demand and supply into equilibrium [11].

Energy storage is gaining relevance in the political discourse both at the European and international levels. The European Commission (EC) published its first guiding documents on a definition and principles for energy storage in June 2016, followed by a EC staff working document in 2017 on the role of electricity in energy storage. These principles were subsequently reflected in the "Clean Energy for all Europeans package", adopted in 2019, by pointing to significant forecasting in implementing storage technologies in European countries reaching 200 GW by 2030 and 600 GW by 2050, leveraging on the renewable energy sharing rate of up to 69% by 2030 and 80% by 2050.

The Frontier Group, in their report [12], discussed the primary importance of energy storage in the future of energy supply. They concluded that energy storage technologies can be an essential part of the future electricity grid, helping to ensure reliable access to electricity while supporting America's transition to 100% renewable energy.

Energy storage is the most effective when used with a suite of tools and strategies dealing with the variability of renewable energy production, such as heat pumps and cogeneration systems. Energy storage also uses energy converted from other forms [7,13]. These systems first absorb energy from a source, transform it into another form of energy, and store it. When the energy demand increases, the stored energy is dispatched [8,13]. Energy conversion could affect the efficiency of the system due to the power losses during the transformation process while responding to the problems associated with energy demand and supply.

The main forms of energy generated in PED as well as used in them are heat energy and electricity. Based on the energy demand of buildings, infrastructures and open spaces, the integrated ESSs can be implemented in order to improve the potential of local renewable energy production, distribution, and supply.

Energy Storage Systems (ESSs) consist of a wide range of technologies according to the classification review issued by Olabi et al. [14]: mechanical, electrochemical, chemical, and thermal energy storage [13]. Each type of storage system offers diverse applications. Mechanical energy storage includes pumped hydro storage (PHS), compressed air energy storage (CAES), and flywheel energy storage [15,16]. Electrochemical energy storage can be achieved with battery storage (lead with acid, Li-ion, Ni-Cd, sodium sulfide (NaS), and ZEBRA) [17]. Chemical energy storage uses hydrogen storage (hydrogen gas, phosphoric acid fuel cells, alkaline fuel cells, fuel cells supported by a proton exchange membrane, molten carbonate fuel cells, and solid oxide fuel cells) and biofuels [18]. Thermal energy storage can be found as latent heat storage, sensible heat storage, and reversible chemical reactions [19]. According to Sandia National Laboratories [20], the most used ESS is mechanically Pumped Hydro Storage (PHS). The order of the remaining types of energy storage based on their use is as follows: Thermal Energy Storage (TES), Electrochemical Energy Storage (ECES), other mechanical ESSs, and the least used system, chemical energy storage, such as generated hydrogen gas. The EU Commission reported that the most used forms of energy storage are PHS, CAES, and liquid air energy storage (LAES) [21]. PHS is the most established technology and accounts for a significant part of global storage capacity. CAES uses electricity to compress air, which is stored underground or aboveground and can respond rapidly. LAES, on the other hand, utilizes electricity to produce and store liquid air, which is then expanded through turbines to generate electricity once again. These technologies offer diverse energy storage methods and vary in response times, capacities, and efficiencies. They play a vital role in facilitating the integration of renewable energy sources and providing backup power in urban areas [22].

Several efforts have been made to research and develop innovative and effective solutions for the implementation of new ESSs in urban areas. The aim is to secure energy supply from renewable sources as part of the overall climate change mitigation pathway towards the decarbonization of cities.

The UK government has allocated over GBP 32 million in funding for five national projects for ESSs. These projects focus on developing new energy storage technologies, including thermal and flow batteries [23]. This will support green innovators throughout the UK, fostering the creation of new jobs and encouraging private investment. Additionally, it will contribute to safeguarding the UK's energy security [24]. This is due to the use of heat for heating, ventilation, air-conditioning, and cooling (HVAC). Heat engines, such as the Organic Rankine Cycle (ORC), can convert the stored heat into electricity for further purposes.

New types of electrical storage devices are capacitors (two conductive layers separated by an insulator) and supercapacitors (double-layer electrochemical capacitors with a large area) [25]. Supercapacitors are large. They can be recharged millions of times without any damage. Superconducting magnetic energy storage uses dynamic magnets to convert electrical energy into magnetic energy, and vice versa. The most used electrical devices for electricity storage are the Battery Energy Storage Systems (BESSs). The general construction of a BESS consists of multiple electrochemical cells connected in parallel or series [26,27].

Liu et al. [28] reported the relevance of hybrid photovoltaic-electrical energy storage systems (PV-EES) for supplying power to buildings. They are divided into three categories according to their working mechanism: mechanical, electrochemical, and electrical storage. In practice, they contain a combination of PVs and already have shown different types of energy storage. They suggested hydromechanical storage of energy as being superior to battery storage. Battery energy storage (BES) with a high response (frequent charge/discharge cycles) saves energy for longer periods for residential users because these systems respond immediately to every change in the electricity supply. These systems have an energy loss issue in the grids, while the stored energy can be saved for extended periods.

According to Liu et al. [28], the focus of ESSs can be separated into technical, economic, and environmental aspects. The technical aspects include energy efficiency, management, size determination, grid integration, exergy efficiency, and modeling with analysis. Economic valuation approaches include methods and metrics such as life cycle cost (LCC), levelized cost, Net Present Cost (NPC), payback period (PBP), Net Present Value (NPV), financial savings, and operational and investment costs. Environmental aspects encompass environmental costs, greenhouse gas emissions (GHG), fuel reduction (from non-renewable sources), Life Cycle environmental effects and pollution, and other emission effects on the environment.

Liu et al. [28] provided helpful directions for energy storage problems that must be solved. They have been focused on Li-ion batteries used in building facilities. These types of batteries have a high investment cost, and energy storage depends on geography, weather, and storage scale with regard to building load. The control strategies for supervising the power distribution and energy use need reliable, smart, and efficient building management. Policymakers must be encouraged and guided to develop more effective incentive strategies for the commercialization of PV-EES technologies.

User-based energy system smart management has been established as a valuable tool for enhancing people's awareness and knowledge about the energy production from RES and for providing the evidence of the economic advantages of the energy systems' maintenance costs by adopting storage technologies and their forecast assessment for future scenarios.

The interest in research on energy storage in urban areas has been growing in the last decade. Figure 1 summarizes published papers linked to the following search topics, namely "energy storage in urban areas", "heat storage in PED", "chemical storage in urban areas", "energy storage in PED", "electricity storage in urban areas", "chemical storage in PED", "heat storage in urban areas", "electricity storage in PED", and "battery and PED" in the Elsevier Publishing House database. Analysis was conducted for the period between 2013 and 2023. According to rapid evidence assessment, interest in this topic is increasing yearly and becoming more attractive. Specific searched topics yielded an exceedingly small number of published papers. This analysis shows that ESSs in urban areas have not yet been extensively explored. Therefore, more extensive research is needed, especially in connection with energy storage and PED.

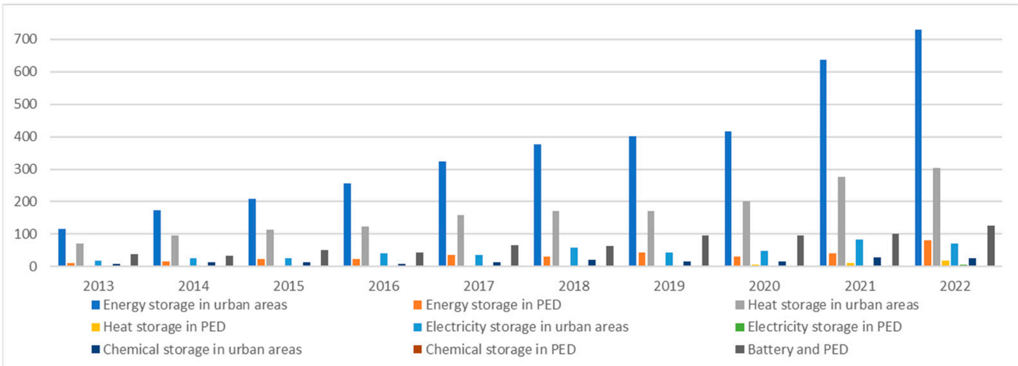

Figure 1. Published papers related to a few different topics about energy storage in urban areas and PED based on the data from ScienceDirect database for the keywords: "energy storage in urban areas", "heat storage in PED", "chemical storage in urban areas", "energy storage in PED", "electricity storage in urban areas", "chemical storage in PED", "heat storage in urban areas", "electricity storage in PED", and "battery and PED".

The literature review highlights the lack of clear solutions to the problem of energy storage in urban areas as one of the main gaps.

Furthermore, the placement of ESSs in urban areas is connected to the location of energy production, the inhabitants of that urban area, and their properties which leads to several critical issues that can be found in the different management models of energy collection and distribution processes in different countries and even more in different urban areas. These processes require further analysis and the determination of a solution that will yield the best results.

This work aims to broaden the scientific and practical understanding of energy storage in urban areas, especially for PED. The main objective of this review is to determine the most suitable types of energy storage that can be used in PED to collect and distribute stored energy in urban areas. Furthermore, this study focused on existing limitations determined by the urban areas for the ESSs. This refers to the installation, safety, legal aspects, and technical needs for its operation. Moreover, the management of energy generation with distribution and interconnection of energy storage units is also of interest in this review. The primary purpose is to analyze the experience of energy storage already implemented in various international projects.

The results of this work regarding different points of view in the functioning of ESSs in urban areas are complex and include different aspects for the realization and operation of these systems. Section 2 presents a general description of the energy storage forms and the related issues about the feasibility of implementation and the regulations currently governing their application.

Section 3 examines the solutions currently applied for energy storage in some urban areas in different international case studies, in order to highlight the peculiarities of interventions related to the energy market and the specific policies adopted to foster large-scale decarbonization paths. Subsequently, the advantages of energy storage systems based on new technology-based ESSs, and their uses in urban areas or installations near the built environment, are discussed in Section 4, providing evidence of the multiple benefits of highly efficient systems when promoting energy mix solutions at the district scale, as a mitigation strategy adopted for the implementation of the Positive Energy Districts model in urban areas.

2. Energy Storage in Urban Areas

ESSs have become a critical issue in energy generation from RES. Rotondo et al. [29] report on energy storage as one of the key points to ensure ecological transitions in urban areas. There are a few separate energy storage methods currently available for the storage of heat and electricity as the primary forms of energy that can be generated directly from RES. Dehghani-Sanij et al. [30] collected and summarized data on a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of CAES, PHS, BES, and hydrogen storage systems. According to that research, CAES and PHS have strengths in terms of low-cost and high capacity, but they need large spaces to host and operate the technology.

On the contrary, high-cost ESSs, such as BES and hydrogen storage, need less space and offer a high response to the distribution of energy requirements. Xylia et al. [31] illustrated the key factors considered for selecting energy storage. These factors are energy density (how much energy can be stored per mass unit), power density (how fast that energy can be realized), storage duration (how long energy should be stored), and costs (how much it costs compared with other solutions).

2.1. Thermal Energy Storage

Thermal energy storage types do not require significant investments. They are prevalent for storing solar heat energy. This is especially true for sensible heat storage demonstrating the lowest energy capacity (heat storage effectiveness). The heat that can be stored is limited to the capacity of equipment, i.e., the amount (volume) of the heat storage material. In general, the primary sensible heat storage material is water. It is a multipurpose material. It can be used as hot water for household needs and heat storage for other purposes. According to EUROSTAT in 2019 [32], the primary energy consumption in EU households was 64.1% for space heating, 14.8% for water heating, 14.4% for lighting and appliances, 5.6% for cooking, 0.3% for space cooling, and the remaining 0.9% for other purposes.

Sensible heat storage is the cheapest energy storage. It uses the different abilities of materials to absorb heat during the heating process [33]. The volume of storage material is proportional to the energy that can be stored. In contrast, the latent heat storage (HS) includes materials that change phase (PCM—Phase Change Material) during heat storage. The process is based on the latent heat characteristics of materials. The phase change is at a certain temperature [34]. Therefore, there must be selected appropriate materials for the required process parameters. In many cases, some expensive materials need to be selected. Furthermore, absorption and adsorption systems show remarkably high energy storage density. Their energy density is up to 1000 MJ/m^3. Alva et al. [35] connected HS in buildings with the use of new building composite materials. This is shown in Figure 2, where different ways of HS are determined for use in buildings.

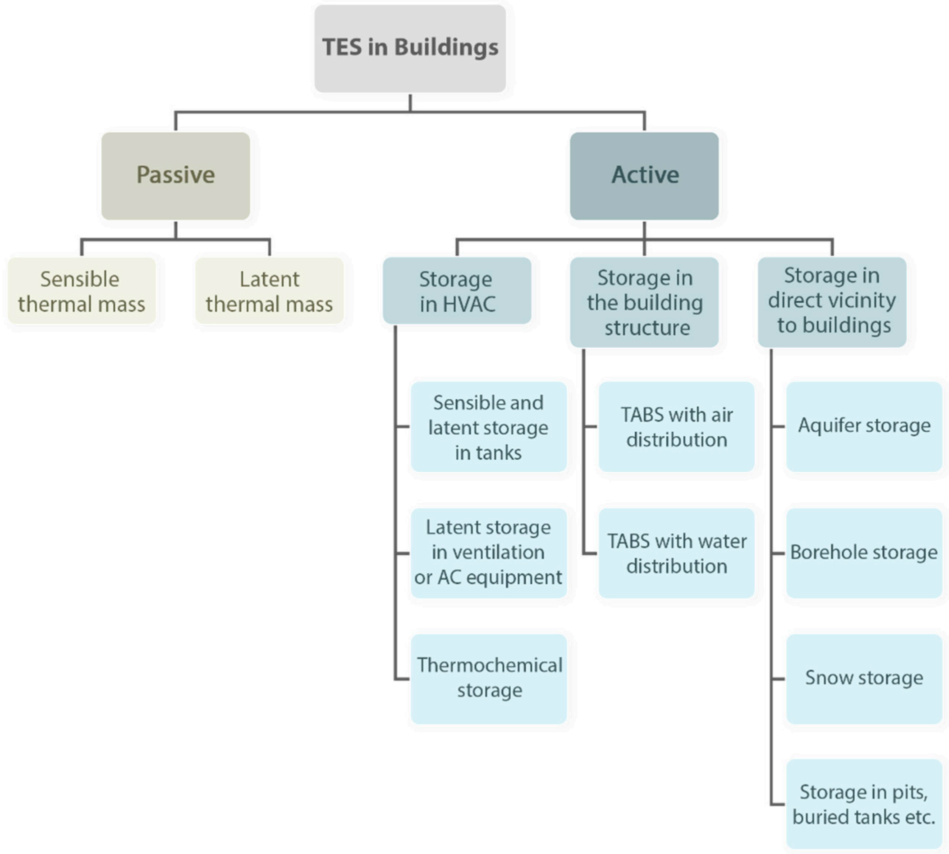

Figure 2. Thermal energy storage in buildings (adapted from [35]).

They divided HS into active and passive storage systems. PCM and sensible HS systems are determined as passive energy storage. Their use is intermittent. On the other hand, active HS is continuously used by HVAC systems in buildings, or these systems are part of the building structure or the neighborhood. Dynamic storage systems are only sometimes possible due to the space and construction that they need. Aquifers, pits, rocks, and brick thermal storage systems exist in urban areas. Denmark uses pits for community HS systems. Similarly, aquifers are used in the Netherlands [36].

Technical Requirements for Applications

Thermal energy storage is a highly promising technology for urban areas. Its principle involves the storage of thermal energy through the heating or cooling of a storage medium. This stored energy can be utilized later for various heating and cooling applications and power generation [23]. There have been innovative advancements in district heating, such as solar thermal district heating systems, large-scale heat pumps, and the integration of geothermal and waste heat. These developments are the most effective when operating at low temperatures [37]. The Giga_TES project aims to create large-scale thermal energy storage concepts for Austria and Central European urban districts [38]. Its ultimate objective is to achieve a 100% renewable energy heat supply for cities [38]. This can be accomplished only with the use of large underground hot water tanks and pits, which will serve as multifunctional energy hubs for future district heating systems. Expansive thermal energy storage technologies, like these, will facilitate the seasonal and short-term storage of a wide range of volatile energy sources, thereby significantly increasing the proportion of renewable energies in the urban energy mix.

The heat energy storage in urban areas is subject to various legal and regulatory challenges, which can limit its widespread adoption. Some of these challenges include building codes and safety regulations [39], as heat ESSs can pose safety risks such as respiratory problems or eye irritation due to some PCMs. Regulations can add complexity and costs to the design and installation of heat ESSs in urban areas.

The relevant regulations have not yet been determined. The installation of heat ESSs in urban areas often requires various permits and regulatory approvals. This process can involve navigating a complex landscape regulation, which can be time-consuming and costly [40]. Furthermore, local authorities may have conflicting requirements and varying levels of expertise to assess the safety and impact of heat ESSs. Integrating heat ESSs into existing energy systems in urban areas can also pose challenges. For example, the HS system may need to be interconnected with the local electrical or heating grid, which may require regulatory approval and negotiation of tariffs and service agreements with utility companies.

Safety must be ensured by the companies that install the equipment by using nontoxic materials for storage, and protecting living organisms from the high-pressure containers that hold materials at relatively high temperatures. Technical requirements refer to meeting the regulations for high-pressure and mid-range temperatures in equipment, and achieving the connection, measurements, and control in the distribution [41]. Furthermore, high-volume units are required for storage. Underground applications can have an impact on the environment. There is rare use of toxic materials. The main challenges are increasing HS capacities and their integration into the energy system with cogeneration (use of the ORC or other types of heat pumps). Moreover, there is a need to provide heat for district heating systems connected to polygeneration systems.

2.2. Electricity Storage (Electrical and Electrochemical Energy Storage)

In 2019, the International Energy Agency (IEA) [31] reported that only 3–4% of electricity generated from RES globally is stored. To avoid a temperature rise of more than 2 °C, energy storage must increase by approximately 280% from 160 GW (2021) to 450 GW by 2050. Batteries have a few strengths that make them a favorable mode of energy storage. They are good for distributed storage, and present excellent configurability, high response time, and high energy efficiency and density [30].

Technical Requirements for Applications

The legal regulations for installing and operating electricity storage systems are widely analyzed due to the many potential problems that these units can cause to the building, neighborhood, and environment when using batteries. Lithium ion, lead acid, lithium iron or other battery technologies can cause acid leakage, toxic material emissions, and explosions. Compressed air represents an alternative electricity storage technology where electricity is used to compress air and store it, often in underground caverns. When electricity demand is high, the pressurized air is released to generate electricity through an expansion turbine generator. Moreover, electricity can be used to accelerate a flywheel through which the energy is conserved as kinetic rotational energy. When the energy is needed, the spinning force of the flywheel is used to turn a generator, providing an additional storage means (United States Environmental Protection Agency, 2023).

The EU Parliament accepted the directive of the EU Council related to common rules in the internal market for electricity (Directive 2012/27/EU). Article 36 is related to distribution system operators' ownership of storage units [42], according to which, distribution system operators cannot own, develop, manage, or operate storage facilities. There are exceptions where storage is fully integrated into the network, storage facilities are an essential part of the distribution system, or the regulation authorities determine it as a necessity. The EU Commission has only published, in 2019, a few regulations on electricity storage and its importance. They are related to constructing a globally integrated, sustainable, and competitive industrial base for batteries in the EU (COM/2019/176) [21,43].

Furthermore, the EU prepared the Batteries Europe platform based on the previous Strategic Energy Technology Plan (SET Plan). According to these plans, the focus is on creating sustainable batteries, including by researchers and stakeholders [44]. The year 2021 was the switch point for energy storage. That was the year when the energy crisis started. That was a reason for finding better solutions for energy storage and regulating those systems.

The implementation of projects for energy storage in urban areas in North America faces legal barriers [45]. Any energy storage installation within a local government area must be permitted, inspected, and approved. For example, indoor or outdoor installations must meet local requirements. Storage system host sites may also impose restrictions on available, permutable space for energy storage that does not meet local jurisdictional requirements. Local governments are still learning about energy storage and developing relevant regulations like fire and safety procedures. As a result, the energy storage installation may take longer as local government procedures catch up with technology adoption. Storage policy integration is a versatile choice that can provide multiple revenues to building owners and developers. However, in some cases, intentionally or unintentionally, policies and programs exclude ESSs. The operating model for ISO-New England wholesale market programs was not designed to accommodate smaller distributed storage resources because it was designed to work with PHS.

Furthermore, some programs have requirements for behind-the-meter (BTM) storage projects [46]. The Federal Energy Regulatory Commission [47] has mandated that independent system operators review and update their policies to accommodate advanced energy storage. As a result, policies in the United States are expected to evolve in the coming years.

The connection of electricity storage systems to the local electricity grid can also pose challenges, as grid operators may have different requirements for connection and operation. For example, some grid operators may require the installation of specialized equipment, such as inverters, to ensure that stored electricity can be safely and efficiently integrated into the grid [48]. In some cases, electricity storage systems may also be subject to net metering policies, which regulate the flow of electricity between the storage system and the local grid. These policies can vary between states and countries and can impact the economy of electricity storage systems, making it more difficult for urban residents to adopt these systems. The operation of electricity storage systems can also be subject to environmental regulations, such as regulations on the disposal of batteries and other components at the end of their useful life. These regulations can add complexity and cost to the operation of electricity storage systems in urban areas.

Electricity prices vary at separate times of the day. Therefore, it is sensible for systems to charge batteries with cheap electricity and discharge them when the price is high. The situation is different in the Netherlands, where the feed-in tariff for electricity is identical to the electricity price.

The main characteristics of batteries are connected with their lifetime and the number of charging/discharging cycles. The negative side of batteries is their short lifetime and the negative influence of low temperatures on the functioning of batteries (cold-climate regions). BES is already included in transportation systems (public and private electric or hybrid vehicles), and its use is significant in the RES demanded by cities. The selection of the battery type can be exceedingly difficult due to rapid and fast changes in the technologies used for electricity storage.

The charge/discharge cycles are limited. Guney and Tepe [49] determined the storage system size and the discharge time. They divided them into three categories: uninterruptible power supply (UPS), T&D grid support, and bulk power management. In the category of UPS power, there are ”located systems” up to 100 kW: high-energy supercapacitors, high-power supercapacitors, high-power flywheels, Ni-MH, Ni-Cd, lead-acid batteries, Li-ion, and flow batteries (Zn-Cl, Zn-Br, vanadium redox). For the second category, T&D grid support includes high-capacity batteries from the first group (high-power supercapacitors, high-power flywheels, Ni-MH, Ni-Cd, Lead-acid batteries, Li-ion, and flow batteries (Zn-Cl, Zn-Br, vanadium redox)), $NaNiCl_2$, advanced lead-acid batteries, and NaS batteries. The third category, "bulk power management", includes only PHS and CAES. The last group and some flow batteries have discharge times measured in hours. In the second group, in general, modules discharge within minutes. The lowest discharge time has high-power flywheels and capacitors, measured in seconds. The capacity is limited.

The storage of electricity produced from RES in urban areas with rechargeable batteries can pose various risks that must be considered to ensure safe and reliable operation. Some critical risks are associated with using rechargeable batteries for energy storage in urban areas. These include battery degradation, fire risk, environmental impact, and grid connection [50]. Rechargeable batteries can degrade over time, reducing their capacity to store and discharge electricity. This can lead to reduced system performance and efficiency and may also pose a risk to the system's safety. Rechargeable batteries can pose a fire risk if not handled, stored, and transported correctly. For example, batteries can overheat or catch fire if damaged, exposed to high temperatures, or subjected to overcharging or over-discharging. The production and disposal of rechargeable batteries can significantly impact the environment, including releasing toxic substances and using finite natural resources. The connection of rechargeable battery storage systems to the local electricity grid can also pose challenges, including the need for specialized equipment, such as inverters, to ensure that the stored electricity can be safely and efficiently integrated into the grid. Rechargeable batteries must be equipped with the appropriate battery management systems to ensure that batteries are safely and efficiently charged, discharged, and monitored [51]. Battery management systems must also be able to detect and respond to any potential safety incidents, such as overcharging or over-discharging, to prevent damage to the batteries or other components of the ESS. Rechargeable battery storage systems must be equipped with appropriate energy management systems to ensure that stored electricity can be effectively integrated into the local grid. Energy management systems must dynamically balance the supply and demand of electricity, considering the availability of RES, such as wind and solar power, and the urban district's electrical load.

Better City and the Cadmus Company [45] presented the advantages and disadvantages of several types of batteries. Lead-acid batteries are a type of electrochemical battery storage that uses a chemical reaction to store and release energy. The most common types are sealed, flooded, valve-regulated, absorbent glass mat, and gel. The structure and used additives provide a variation in lifetime and performances as benefits. Examples of applications include resilience, limited grid support, peak load management, renewable energy stabilization, and UPS. With an estimated 150–300 $/kWh cost, the life expectancy is 5–10 years. Benefits include being well-known, reliable technology, which can withstand deep discharges, but with a shorter life expectancy and a lower cost. The disadvantages include a reduced life expectancy due to fewer useful cycles. They have a lower energy density, meaning that more space is needed to store the same amount of energy as other technologies.

Lithium-ion batteries [31] are a type of electrochemical battery storage that stores and releases energy through a chemical reaction. There are numerous variations, but all contain lithium, cobalt, nickel, manganese, and aluminum. Similarly, they are used as lead batteries for resiliency, grid support, peak load shifting, renewable energy firming, and UPS. The expected lifetime is 10–15 years, costing 250–1500 $/kWh. The advantages are high energy density that allows for high-power applications, deep discharges, and a long cycle life. These allow more intensive use and a longer life. The disadvantages are higher price than traditional ESSs, requiring a sophisticated control system to mitigate fire risk, materials are not readily recyclable, and toxic waste is generated.

Flow batteries [52] represent another type of electrochemical storage that charges and discharges electricity by using a system of tanks, pumps, dissolved chemicals, and chemical reactions. This technology is still in its initial development stage and is waiting commercialization. Its usage benefits are related to resiliency, grid support, peak load shifting, renewable energy firming, UPS, and bulk power management. It costs approximately 680 to 2000 $/kWh with a lifetime of 10 to 20 years. Benefits include being safe, easy to scale up, well suited for higher capacity (duration) uses, and having a long useful life. On the other hand, the disadvantages are relatively excessive costs, low efficiency (less than 70%), low energy density and thus taking up more space, and high maintenance due to pumps, which are currently in the initial stages of commercialization.

Batteries have a high environmental impact. This is especially significant in the case of battery disposal and recycling. Moreover, their production relates to environmental pollution and landscape modification: mining, manufacturing, use, collection, transportation, and storage. Batteries are not dangerous during their usage [30]. The most common primary types of batteries used for portable devices are not rechargeable. This means that they have no charge/discharge cycles; they are used only once. The metals used in the production of batteries include lead (Pb), lithium (Li), nickel (Ni), cobalt (Co), zinc (Zn), manganese (Mn), magnesium (Mg), mercury (Hg), silver (Ag), cadmium (Cd), vanadium (V), potassium (K), titanium (Ti), chromium (Cr), sodium (Na), tin (Sn), aluminum (Al), iron (Fe), copper (Cu), indium (In), silicon (Si), antimony (Sb), lanthanum (La), and cerium (Ce). The non-metals used include carbon or graphite (C), fluorine (F), chlorine (Cl), bromine (Br), sulfur (S), and germanium (Ge). Because of the geographical location of metal sources (often in unstable or controlled economies) and the depletion of the most accessible sources first, increased battery manufacturing impacts natural resource access and economics. Furthermore, some of these materials are valuable (Ag) and are used as currency, while others are expensive (In and Hg), or rare (La and Ce). Additional quantities of minerals from existing sources and discoveries must be generated to meet the increased demand for metals such as lead, zinc, lithium, aluminum, copper, and so on. The mining industry presents significant environmental and social issues, particularly in less developed countries with lax or corrupt regulatory oversight, and these may worsen if demand forces prices upward. All these factors and issues are indirectly related to battery usage. Therefore, batteries seem to be environmentally friendly, but they are highly polluting materials.

Batteries can be damaged during their usage, and leakage of their contents can cause damage to living organisms. Alkaline batteries contain corrosive electrolytes. Pb-acid batteries contain corrosive acids and very toxic lead. Similarly, very toxic materials are present in Ni-Cd batteries. Ni-MH can self-combust in the case of damage. Lithium batteries have a substantial risk of fire and explosion. GHG emissions per kg of battery are slightly higher than direct CO_2 emissions, and Pb-A emits the least CO_2. The average emissions for each battery are less than 30 g/kg of battery, excluding SO_x emissions from Ni-MH and Ni-Cd batteries. Furthermore, the relative average change among batteries for each emission is the same. In general, Pb-A batteries emit the fewest contaminant emissions of any battery.

Raugei et al. [53] analyzed the impact of using electricity storage on PV with Lithium-ion batteries on the LC global warming potential within their storage duration scenarios. They negatively impacted the environment and increased the warming potential between 7 and 30% compared to PV systems with no electricity storage system. Energy storage in batteries is approximately 400 $/kWh (in 2016), rapidly increasing in the forthcoming years. Due to these facts, adding lithium-ion battery storage to photovoltaics does not impact their overall sustainability.

2.3. Chemical Energy Storage

Chemical energy storage involves using chemical compounds and the chemical reactions between them for storing any other form of energy. Some compounds can be very reactive and some of them very explosive. Therefore, this kind of energy storage requires caution. The use of chemical storage systems, such as propane, butane, ethanol, biodiesel, and hydrogen in urban areas is subject to various legal and regulatory challenges, which can limit their widespread adoption. This is related to current regulations and standards regarding storage and the transport of these components.

The most common fuels used in urban areas are coal, natural gas, diesel, gasoline, liquefied petroleum gas (LPG), propane, butane, ethanol, biodiesel, and hydrogen [54]. All these fuels are sources of chemical energy. Only ethanol, biodiesel, hydrogen, and some hydrocarbons can be produced from other materials as renewables. Therefore, they are popular as clean or sustainable fuels for urban areas. Regarding chemical energy storage, hydrogen and Synthetic Natural Gas are the most suitable chemical energy storage materials [55]. Recent research has developed mechanisms that use reversible thermochemical reactions. Specific reactants are ammonia on one side and hydrogen with nitrogen on the other side of the reaction. The reversibility of chemical reactions in both directions comprises the charging/discharging cycles [56].

Hydrogen as a product of energy used in chemical or electrochemical processes improves environmental performances with minor negative effects [57]. The efficiency is low due to the low energy density (low enthalpy of oxidation). In contrast to hydrocarbons, hydrogen has the highest enthalpy at 142 kJ/kg. Hydrogen can exist in three different forms due to the production process [37]. Hydrogen produced from fossil fuels is grey hydrogen. Blue hydrogen is produced from fossil fuels where the carbon emissions are captured and reused. Finally, green hydrogen is produced from RES without carbon emissions. According to the Det Norske Veritas group (DNV) report [58], the total hydrogen production is 5% of the estimated global energy demand for 2050. That is one-third of the hydrogen needed for net zero emissions. Hydrogen has a fast penetration in the market. The main advantages of hydrogen energy storage are that it can be stored for a long time with low losses, and the combustion product is pure water. [58]. Hydrogen storage uses hydrogen pressurization and the absorption of metal hydrides, adsorption of hydrogen on carbon nanofibers, and hydrogen liquefaction. Pressurized hydrogen can be stored at 200–250 bar (sometimes 350 bar). The efficiency of this storage system depends on its high storage pressure. In the case of 700 bar storage, extremely high energy is used [59]. Similarly, metal hydrides depend on the ability of their components to adsorb hydrogen. Hydrogen stored in metal hydrides and pressurized hydrogen require cooling and heating during charging and discharging in storage tanks. This is a large part of the energy lost, or it can be used for other purposes. The concept of Power-to-X gives a product X that is efficiently distributed on a large scale of energy storage for extended periods [60]. Fuel cells are quite interesting devices for converting hydrogen into electricity. This is a clean and efficient way of producing electricity, except when hydrocarbons are used as fuel. In the case of hydrocarbons, carbon dioxide is produced as an emission from processes in the fuel cell. Fuel cells are excellent for long-term energy storage, but their price is extremely high because of the components used, such as platinum [61]. The key issues are the cost of storage, storage period, and repetition of charge/discharge cycles. Regarding energy storage, fuel cells absorb stored chemical energy and convert it directly into electricity by the use of a specific fuel type. [62]. Fuels can be hydrogen used with oxygen as fluids that pass through different electrodes (anode and cathode), form water, and generate electricity with some amount of heat [63,64].

Technical Requirements for Applications

According to the EU Commission, hydrogen as fuel and an energy storage medium is high on the list of plans in the EU energy system. The first regulation regarding hydrogen for energy storage was announced in 2020 as the "EU strategy on Hydrogen" (COM/2020/301) [65]. The main concern is the source of hydrogen (it must be from RES). The EU Commission proposed the establishment of a global European hydrogen facility (EU hydrogen Bank) to create investment security and business opportunities for European and global renewable hydrogen production (COM (2023)156) [65]. This shows the importance in EU policy of hydrogen as a fuel and energy storage material. There are also some initiatives such as "Clean Hydrogen Partnership", "European Clean Hydrogen Alliance", and "Hydrogen Public Funding Compass" involved in future research and implementation of the use of hydrogen in the energy system [65].

The storage capacity when using hydrogen is limited. Its volume can take up a significant part of facilities. Fuel cells, especially hydrogen-based fuel cells, have energy efficiencies of approx. 60%. When formed waste heat is used, its overall efficiency is up to 90% [66]. The capacity of fuel cells starts at 100 kilowatts and can be extended flexibly to a range of thousands of watts. Thanks to their plug-and-play design, fuel cells have a fast and simple installation process. They are suitable for flexible integration into different systems. Hydrogen fuel cells have a minimal impact on the environment and are suitable for urban environments. They are good as an energy resource for clean, pollution-free, highly efficient, flexible, and promising microgrid applications. They provide continuous operation and do not require recharging [67]. This makes them an essential facilitator for energy transition, especially in urban areas, buildings, industrial facilities, and data centers. However, it should be noted that while fuel cells have many benefits, they also have challenges to overcome, including fuel cell costs and hydrogen storage and distribution [68].

Another technology uses solar radiation for direct generation of hydrogen. $Ru(bpy)^{2+}$ can split water into hydrogen and oxygen via a photoreaction upon exposure to the Sun [57]. Formic acid in the presence of Ruthenium forms hydrogen and carbon dioxide. Carbohydrates can be transformed via a chemical reaction to produce hydrogen. The storage density in carbohydrates is the best for hydrogen chemical storage. A similar reaction can occur for semiconductors. Hydrogen can be used in two forms for energy storage, namely gas or liquefied, and as a solid in the form of metal hydride. The liquification requires unique cryogenic methods and high-pressure equipment. Due to this, the infrastructure cost for storage and distribution is extremely high. It also includes electronic devices for control and safety. Energy stored in hydrogen can be used directly as hydrogen in fuel cells and special combustion engines for cars. Furthermore, hydrogen can be used for heat generation in later processes (Rankine cycles).

Hydrogen storage depends on the form in which it needs to be stored. This can be as pure hydrogen in the form of pressurized and liquefied hydrogen but also connected within a molecule of chemical components such as metal hydrides, ammonia, formic acid, carbohydrates, liquid organic hydrogen carriers, physisorption, carbon materials (fullerenes, nanotubes, grapheme), zeolites (metal–organic frameworks, covalent organic frameworks, microporous metal coordination materials, clathrate), glass capillary arrays, glass microspheres, and organo-transition metal complexes. Physisorption is a method for hydrogen storage in which different porous materials absorb hydrogen on the surface. The best results have been obtained with nanotubes and zeolites. Compressed hydrogen is a simple form of storage using compression but is inefficiently related to volumetricity and gravimetry. However, cryogenic liquification can reduce the volume by more than half. Therefore, the second form of hydrogen storage is more efficient. Chemical reactions, such as ammonia (the reversible reaction of hydrogen and nitrogen gases), are also used for hydrogen storage. Another reaction is the formation of a metal hydride. These products can release hydrogen upon heating. They are safe for storage, but some are not safe for humans. They are toxic or irritants. Moreover, they are aggressive in the presence of moist air. The storage efficiency is 2% of the total mass.

According to the study by Niaz et al. [57] the cheapest hydrogen storage is liquefied hydrogen storage (approximately 6 $/kWh). More expensive is storage as metal hydride (approximately 8–16 $/kWh).

2.4. Other Types of Storage

Other Types of Storage Technologies Used in Urban Areas

Mechanical energy storage is another type of energy storage, but it requires specific conditions and configuration of the environment. CAES uses compressed air for energy storage via the process of compression. As previously mentioned, this type of energy storage requires underground space (caves) [15]. PHS can be considered an environmentally friendly technology but with some concerns in terms of biodiversity. These systems are exceptionally reliable and have a long lifetime. The storage efficiency is the highest compared to the new energy storage technologies. PHS has options for wind turbine parks for the storage of generated electricity by using small-sized reservoirs [15].

Nevertheless, PHS has become less popular due to the impacts on nature. The largest energy storage capacities by their type are given in Figure 3 (percentage of stored energy by type of storage facility built in European countries) and Figure 4 (percentage by the number of plants for energy storage based on the type of storage system in European countries). Mechanical energy storage is the most efficient and used form of energy storage in general, but it is primarily suitable for industrial-sized facilities [20]. The number and the type of energy storage units by country in Europe can be seen in Appendix A.

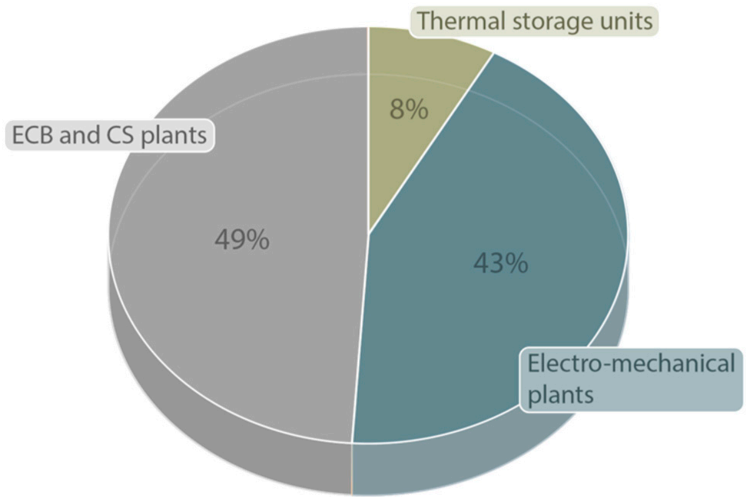

Figure 3. Chart of the percentage of stored energy by type in storage facilities built in European countries [20].

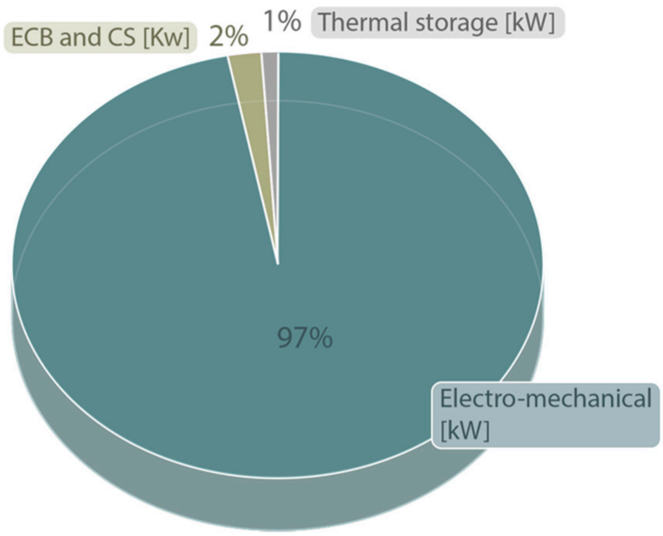

Figure 4. Chart of the percentage by number of plants for energy storage based on the type of storage system in European countries [20].

It must be mentioned that all these energy storage plants are not related to urban areas. They are in general use. Furthermore, some of them can be regarded as "virtual" ESSs.

According to the analyzed data, all the mentioned ESSs are compared on the basis of differences in energy density, power density, storage duration, costs, regulations, technical requirements, environmental impact, safety, and risks. The main aspects of these comparisons are given in Table 1.

Table 1. Summarized comparison of data for different energy storage systems.

	Heat Storage	Electricity Storage	Chemical Storage	Mechanical Storage
Energy density	Aluminum = 2484 [kJ/m^3 °C] Brick = 1813 [kJ/m^3 °C] Cast Iron = 3889 [kJ/m^3 °C] Concrete = 2122 [kJ/m^3 °C] Water = 4190 [kJ/m^3 °C] Depends on filling material [69]	2540 MJ/m^3 [70]	130 MJ/kg (1330 MJ/m^3) Hydrogen [71] 26.8 MJ/L bioethanol [72]	Depends on plant performances
Power density	Sensible: 25 PCM: 100 [kWh/m^3] Chemical: 300 [kWh/m^3] [73]	Max. 560 Wh/kg (LiM) [74]	0.56–3.18 kWh/L (0.58–3.33 kWh/kg) [71]	Depends on plant performances
Storage durability	Depends on the temperature of storage (temperature difference with outside temperature) Short-term Sensible—days PCM—hours Chemical—hours [73]	Depends on technology (from few days to few months)	Infinite (stable chemical compound)	Long-term (depends on evaporation, leakage, etc.)
Efficiency [%]	Sensible: 50–90% PCM: 75–90 Chemical: 75–100% [73]	<70 [31]	99%	Max. 70–85% [75]
Costs	Sensible: 0.1–10 PCM: 10–50 Chemical: 8–100 [73]	250–1500 (approx. 400) [31]	0.030 liquefied hydrogen (approx. 6 $/kWh), metal hydride (approx. 8–16 $/kWh) [57]	Depends on country
Regulations/ Regulations/limits	Building codes and safety regulations [39], complex landscape regulations. Many laws and regulations need to be made.	The most detailed regulations. Many obligations for all parts of the system. But still, regulations should be changed on time due to the rapid development of electricity storage technologies. The main regulations are given by EU directives [42] and US government [45] in corresponding regions. Country and local regulations need to be declared equally, everywhere. Great differences between community regulations even in the same country.	"EU strategy on Hydrogen" (COM/2020/301) [65]. The favorable chemical energy source and storage is hydrogen. Other chemical storage materials are prohibited or there are no regulations for them in urban areas.	There is complete coverage by regulations due to the use of the oldest way of storage.
Technical requirements	High volume requirement. In many cases storage is underground tanks or caves.	Many different devices can be required. The problem is the ownership of devices and land. Mostly available for all stakeholders.	High volume of storage for gases (hydrogen). All materials are explosive and must have fire control systems. Fuel cells are promising, but they have high prices.	CAES requires underground space (caves) [15].
Environmental impact	Landscape change or underground works. Use of dangerous PCM.	Appropriate LCA of batteries can minimize the footprint. Risks of leakage of various toxic materials, dangerous metals.	Hydrogen practically has no impact on the environment. All others can be toxic.	PHS changes the landscape, nature and environment [15].
Operation safety and risks	In rare cases there is toxicity. Most applications are safe. High-pressure and mid-range temperatures are the main concern.	Operation with electricity storage can face battery degradation and fire risk [50]. All systems have good control systems.	Fire and explosive safety measurements are required.	Minimal risks

3. Applications of Energy Storage Systems in Urban Areas

The EU's so-called "European Green Deal" and "Fit-for-55" package make energy storage, and battery storage units in particular, a crucial factor [76]. According to their plans, the energy production from RES should be increased to 55% by 2030. Therefore, many new energy storage units are required. The focus is on batteries. The World Economic Forum predicts a 14 times increased need for batteries by 2030 than today. The energy crisis in 2021 moved the EU towards the transformation of energy systems and an increase in their flexibility. This demands units to store energy in substantial amounts for different lengths of periods. The European Commission published the first guide for energy storage related to electricity in 2016 [77]. That guide was adopted in 2019. In 2023, the EU Commission adopted recommendations for energy storage. The recommendation demands broader energy storage deployment, considering the double role of consumer–producer. The future energy system in the EU is planned to be bidirectional between all participants in the system and ESSs as a vital part of it [43].

The US Energy Storage Association (ESA) [78] determined the dual usage of energy storage units. Energy storage has a basic function to store energy but is used in energy transition to the distribution network. Therefore, the ESA defined five principles for functioning dual usage storage systems. Their tariffs must allow energy storage resources to participate in transmission and market services (Principle 1). Storage-as-transmission projects seeking services in organized markets should not benefit from timing differences in the transmission planning process (Principle 2). For dual-use storage, various combinations of full vs. partial cost recovery and market revenue crediting can be considered (Principle 3). Companies should implement measures to mitigate potential market distortions caused by dual-use storage (Principle 4). Because the company bears the burden of reliability, employees can maintain control over the delivery of a dual-use storage asset for transmission operations (Principle 5).

ESSs can be divided into three main groups: shared residential energy storage, shared local energy storage, and shared virtual energy storage. The shared residential energy storage is an energy storage facility interconnected with the grid network and the energy is used during the peak period. The shared local energy storage is a system with a capacity of between 20 kWh and up to a few hundred. The storage system is placed between the meters and the transformers. It is the property of the community or the property of the state. Virtual energy storage can be of any size and in any place connected with the grid to the community, or national or international energy network [50]. Sander van der Stelt et al. [79] divided urban ESSs into household and community energy storage (CES) systems. Parra et al. [80] determined that CES is referred to as "ESS" located at the consumption level with the ability to perform multiple applications with a positive impact for both the consumer and the Distribution System Operator (DSO). In practice, HES deploys separate battery storage for each household. An ESS is located at the consumption level with the ability to perform multiple applications to manage demand and supply, positively impacting on the consumers and system operators, according to van der Stelt [79]. Roberts and Sandberg [73] proposed CES as an intermediate solution between residential and distributed energy storage. CES, according to Koirala et al. [50], is an ESS with community ownership and governance that generates collective socioeconomic benefits such as higher renewable penetration and self-consumption of renewables, reduced dependence on fossil fuels, lower energy bills, revenue generation through multiple energy services, and increased social cohesion and local economy. They analyzed types of energy storage suitable for the community level. The most usable hydro pump and compressed air storage are not suitable at the community level, which is related to the size and construction. The best-fit batteries (electrical storage) and sensible and latent thermal storage (water, aquifer, pit, rocks, and bricks) suggest a great perspective in regard to hydrogen energy storage.

Fichera et al. [81] developed a methodology for the modeling of energy production and distribution systems with energy storage in PED. It includes the production of renewable energy on site, energy storage to cater for the mismatch between production and consumption, and distance sharing among connected buildings within the spatial boundary. Modeling includes every household's daily electrical or heat energy consumption, bidirectional energy route as peer-to-peer consumption. This can be available only with the use of energy storage depending on the type of energy (electricity and thermal). The following assumptions are determined: Energy flows can be shared from a positive to a negative energy balance building. Energy production is initially used to meet buildings' energy requirements. Excess production (which cannot be stored or distributed further) is first distributed and then stored. It is sent to the main grid, and buildings with residual demand are supplied from that main grid. The energy storage facilities are common for the whole district.

Ambrosio-Albalá et al. [82] analyzed Distributed Energy Storage (DES), focusing on electricity. According to them, the position of DES should be near the energy demand loads in urban areas.

Stephenson et al. [83] analyzed people's energy culture and behaviors in the acceptance of modern technologies, especially in the wind farm case. Before and after the wind farm was operational, community members and stakeholders were interviewed to assess their perceptions of the development. Various environmental, socioeconomic, and socio-political factors influenced the community's perceptions, but they also changed over time. Although negative perceptions were found before and after the installation, the community collectively became used to the turbines, and attitudes changed for the better. Moreover, Kadar et al. [84] conducted research on the perception of Renewable Energy, Climate Change, and Policy Awareness among people in Israel. According to that study, 55% of participants had seen a solar or wind system, while 45% had not. This means that a lot of people do not have enough information about RES. More than 14% felt uninformed, while 35% of respondents could not elaborate on their awareness of solar energy. These kinds of studies are important to understand the information that needs to be shared with the population of an area, district, or city where a project plans to invest in facilities for the use of renewable energy or its storage. Many aspects must be considered, like noise, visual impacts, environmental effects, and any other factor that would influence citizens' average life. The study of Cornwall by Wilson and Dyke [85] shows the transparency of the entire process in application and obtaining the evidence on the direct or indirect benefits of citizens will improve the positive opinions of people regarding such projects. Based on similar case studies, Stephenson et al. [83] created a model of influences related to citizens' opinions. The energy culture model is separated into three parts as energy practices (energy price structure, social marketing), cognitive forms (education, education, demographics), and material culture (regulations for buildings, clean air, efficiency rating, home income, available technologies).

Interestingly, people can change their acceptance of innovative technologies within aspects such as ridesharing and events to develop "energy literacy" in energy practices. A material culture change is related to a partnership with local suppliers, exchange of technical advice within the community, bulk purchase of EE products, and home insulation projects. Cognitive norms can be changed by visiting speakers giving talks on sustainability, events to develop "energy literacy", community "visioning" workshops, and community meetings on survey results. Cherry et al. [86] carried out a similar analysis of low-carbon technologies. Perceptions that a technology is promising or strategically important significantly increase the likelihood of support for its development and deployment, while perceptions that a technology will harm the environment decrease support. The most intriguing findings relate to the impact of economic interests and cultural worldviews. Economic interests have been discovered to influence the level of support for deploying related energy technologies but not for public development funding. Households that rely on coal for economic reasons supported the deployment of Carbon Capture and Storage technology but not wind technology. In contrast, households that rely on wind resources supported deploying wind energy technology but not Carbon Capture and Storage technology. The fact that the findings have been divided between two technologies provides unusually convincing evidence that economic interests play a significant role in determining public support for low-carbon energy technologies [86].

According to the results of the cultural worldview, individual orientations affect the level of support for development that is funded by public funds but does not affect the deployment. People with more hierarchical and individualistic worldviews are less likely to support development. These outcomes are not technology-specific, consistent with a broader relationship between worldviews and government R&D funding.

Using ESSs in urban areas can result in landscape changes, impacting the environment and local communities. Some key risks associated with landscape changes include physical, visual, and noise impacts. ESSs could occupy much space in cities, especially when large-scale batteries or hydrogen storage systems are used. This can lead to the loss of green spaces such as parks and public gardens, and the displacement of wildlife and other natural habitats. ESSs can have significant visual impacts too, especially in densely populated areas or near sensitive cultural or historical sites. This can cause changes to the local landscape and have an impact on the character and esthetic quality. ESSs can produce noise, mainly when large-scale batteries or hydrogen storage systems are used. This can be disruptive to residents and lead to conflicts between the operator of the ESS and the local community.

Proka et al. [42] provided information about the project, "Neighborhood Battery System" (NBS), in Rijsenhout, Western Netherlands, near Amsterdam. The project initiative came from one of the Dutch natural gas and electricity suppliers, Liander. It became a hybrid energy distributor (mixed energy sources). Their project involved prosumers, i.e., the local residential electricity producers from renewables to store electricity in small battery storage as a decentralized model. The NBS project created innovative collaborative business models between the established regime and emerging renewable initiatives [87]. The Rijsenhout pilot installation is less than 200 square feet (approx. 18.6 m^2) in size and has a 128 kWh battery system that connects the rooftop solar panels of 35 households and serves as a temporary power storage unit. During the day, it stores excess solar energy and releases it as needed during peak hours. It also saves EUR 25,000 in grid reinforcement costs and stabilizes grid power by up to 20 V. In general, by maximizing solar power, the system contributes to energy conservation and carbon reduction.

Proka et al. [42] analyzed NBS projects from different views, such as technologies and infrastructures, user practices, cultural significance, knowledge base, sector structure, policies and political power, and organizational logic. The societal benefits of this project are benefits for public companies, commercial parties, and end-users. These include energy security, power quality, improved public-client connection, reduced energy cost, increased autonomy, social cohesion, energy awareness, lower financial cost for the operator, higher efficiency, safer solutions, no cost in residential space, higher capacities, less administration, and many more. Interestingly, the NBS projects faced many obstacles during every segment of implementation. The network operator had problems with the legislation, lack of social business case (bottleneck in financial transactions), uncertainty in energy price development, low social interest, limited customer knowledge and related concerns, safety issues and health concerns, consumer preference for household batteries, privacy issues, expensive technology, ugly installations, and high financial cost. In other words, the renewable energy perspective faced the following barriers: lack of additional value, taxation issues, permit issues, uncertainty in roles and responsibility for ownership, control and maintenance, unclear cost-benefit distribution, lack of knowledge about batteries and public awareness about energy, lack of space and place, esthetics, ethics issues, lack of complete control in energy delivery, low-cost/benefit ratio, and emission of low-frequency noise.

Bruck et al. [88] analyzed already realized PED from the techno-economic perspective. An important part was storage. They reported about thermal storage, batteries, and possible usage of hydrogen storage as the most used types of storage in realized systems.

Alva et al. [35] overviewed the use of TES. They analyzed industrial HS systems for electricity generation. However, they included TES applications in district heating systems. Power generation is based on solar fields with storage in molten salts. The systems used in the districts have water as the HS medium. Storage is designed underground, and the first heat source is solar heat, but additional ones are natural gas, biomass, or fuel oil. The specific case is district heating in Kungalv, Sweden, where the main heat source is industry (industrial systems), and the second is waste incineration. A similar district heating system was adopted in Linz, Austria, where the main heat source comes from the ORC as plants for electricity generation from wood waste [89].

The ESS can have a transmission role in energy generation and distribution. The ESA determined in their published report [90], that energy storage should be considered a transmission solution in the normal course of transmission planning processes. Storage-as-transmission (SAT) differs from traditional transmission solutions and deserves treatment that does not unduly penalize those differences. SAT solutions should be studied using a process and timeline in which approval, development, and deployment meet the transmission system planner's objectives and/or needs. Any capable and, where appropriate, qualified industry participants should be able to propose, develop, own, operate, and receive fixed cost recovery for any SAT solution. Transmission system operators must make storage dispatch decisions to provide transmission services. All SAT providers should be able to recover costs through transmission rates. Transmission incentives should be available for technologies like SAT that add value or save money by supplementing existing infrastructure. SAT round-trip losses should be treated in the same way as conventional transmission line losses. The position of the state-level policy [91] is following energy storage targets which should be used by states to establish or support storage market growth. Existing state policy objectives should guide storage goals' size, structure, and timeline. State storage goals should correspond to the storage required to meet established policy objectives. The state policy goals should develop storage target metrics, review, and accountability mechanisms. Energy storage goals should include various project sizes, types, and business models. Diversity should be aimed at developing a state storage market that offers the broadest range of storage benefits and allows for the evaluation of various storage applications.

4. Experiences and Possible Solutions for Urban Areas

4.1. Energy Storage and Communities

Many experts agree that future cities will be "energy storage cities". They should have integrated energy storage, with Internet of Things (IoT) as the link to thermal and electrical grids [31]. These technologies will enable smart cities and communities. Some technologies are challenging to be accepted by some communities with a reason. Urban communities' acceptance of innovative technologies is highly important for establishing new systems for PED or ecocities. Related to the report of Energy Community London [92], typical urban community energy projects include photovoltaics, energy efficiency, low-carbon transport, energy storage (with a focus on batteries), and heat pumps.

Thomas et al. [93] analyzed the opinion of people in the UK about ESSs. According to their study, people did not think of an ESS as part of their household, but most expressed the opinion that the system is somewhat a substation in the electricity grid. Many expressed concerns about esthetic and spatial impacts, efficiency, and technology issues. They had a negative perception of battery composition, recycling, and pollution. In addition, policymakers must find a way to socialize the costs of vulnerable groups, whether through centralized storage, novel ownership, service, or tariff structures. Furthermore, according to the experience of this review's authors, people are afraid of using IoT as a way to be controlled alongside hacking of the system having negative consequences for the residents. According to Xylia et al. [31], the main drivers of energy storage are decarbonization, decentralization, and circularity.

Until 2018, more than 2800 cooperatives created energy communities in the EU [94]. Most of them are in Germany (1000) and the Netherlands (400). Local communities are increasingly engaged in producing, saving, sharing, consuming, and exporting locally, due to recent developments. These include changes such as the implementation of appropriate policies, the reduction in renewable energy costs, emerging information and communication technologies & IoT, and environmental awareness within community goals such as grid independence.

4.2. Impact of Energy Storage on Urban Areas and Prosumers in Practice

Several reports show the positive impact of energy storage in urban areas. According to the Frontier Group [12], energy storage has a positive impact on gas emission reduction, especially according to the reports of global environmental protection organizations.

It foresees excellent opportunities of HS for many different applications. One is essential, i.e., using stored thermal energy in classic thermal power plants for electricity and district heating production. Similarly, the winter cold can be stored for air-conditioning on summer days. On the contrary, batteries are not as efficient and economical for investing in large electricity storage facilities. It is better to convert electricity into more efficient energy for storage and use, like chemical, potential, or thermal energy. The positive side of batteries as electricity storage units as part of electricity grids is the continuous electricity supply during big disasters when the electricity supply from the national electricity network cannot function because of a specific disruption.

Moreover, ESS integration is crucial for exchanging stored energy and its distribution. He et al. [95] discussed the integrated urban energy system (IES). The IES takes energy from solar, wind, geothermal, waste heat, biomass, and other sources. The energy from these sources supplies the power network, the hydrogen system, the gas network, heat network, and the cold networks. Between the supply sources and urban supply networks, there is an exchange of energy within the energy conversion systems like Combined Cooling Heating and Power unit, heat pumps, absorption refrigeration, steam reforming, P2G, cogeneration systems, chillers, and the storage systems (electricity storage, HS, cold storage, and fuel cells). He et al. [95] suggested the process of IES planning. They determined five main steps. The first step (determination of user needs) involves basic conditions, targets, multi-energy forecasting, and all feedback from the other four steps of planning mechanisms. All energy demands, supplies, distribution, and prices are analyzed when these inputs are collected with the aim of creating a reasonable plan. The scenario or plans need further uncertainty analysis. The results of the uncertainty analysis are fed back to the first step. In that case, revisions are made at the first and second step. When the uncertainty analysis satisfies the requirements, the next step (Step 3) is to show the plan to the public as well as social factors. With that, sources are integrated (Step 4) and evaluation feedback (Step 5) is prepared and sent to Step 1. In this IES planning process, the ESS should be included as supply and demand needs.

Portland General Electric [96] showed energy storage planning in its energy distribution planning process. Portland General Electric conducted a separate case study for storage with the Resource Optimization Model. According to the case study, 90% of the storage amount came from services that lasted less than an hour. The most important drivers in establishing ESSs and planning them are as follows: bring cost reductions (commercial and industrial customers are under pressure to reduce total energy expenditure, financing flexibility); improve the supply quality (a great emphasis on supply resiliency and redundancy requires reliable solutions); improve sustainability (with a greater emphasis on sustainability and regulatory compliance, required of a comprehensive energy strategy); drive scalable solutions (large clients want scalable enterprise-wide solutions for monitoring, benchmarking, and optimizing energy costs); simplify operations (customers want to simplify operations and refocus on core business as corporate energy management functions have become more complex).

Cadmus Group [97] gave some directions on planning energy storage. They suggested "storage development consider storage as a resource in the utilities' resource plans". Moreover, Cadmus Group suggested the following ways of including energy storage as a resource utility: storage should be treated as a distinct resource type in integrated resource plans; distributed energy resources must be considered in distribution planning; more transparency and collaboration are required in the planning process to assist distributed energy resource developers; customer research is required to understand customer storage desires; non-wire alternative (NWA) planning should include detailed feeder analysis; distributed solar capacity should be increased and storage benefit utilities added.

Households are the elementary unit for the integration of any type of energy storage system. Sander van der Stelt et al. [79] analyzed different scenarios concerning households with HES and CES. All processes in charging and discharging, and using electricity from the grid, are analyzed, and managed by the information systems, the home energy management system, and the energy management system. According to this study, the infeasibility of both storage systems comes from the investment costs per kWh. As a result of that analysis, there is a suggestion for further optimization of battery-share allocation in CES.

When there are energy peaks in demand and production, and severe weather conditions, energy generation looks for incredibly flexible systems that will immediately react to the current conditions. CES has a significant role in flexibility and energy balancing of the system. Koirala et al. [54] analyzed CES as a social and technical innovation for flexibility and energy balancing. They gave the five keyways to utilize the flexibility of CES: energy storage, energy conversion, supply-side flexibility, demand-side flexibility, and interconnection and grid reinforcement. Many diverse types of energy storage technologies are used and developed, which can be classified according to the materials used, the form of energy stored, their functions, response time, and storage duration.

The main energy carriers in 2050 will be electricity and hydrogen [94]. So, the global transition in energy supply and the type of energy used for required energy depend on the electrification and production and storage facilities for hydrogen. The same report gives the scenario for Europe (excluding the Russian Federation and Ukraine) in 2050. Based on that, the energy demand will decrease by 21% (by increasing energy efficiency), electricity will satisfy 43% of energy demand, and hydrogen will cover more than 9%. There is a prediction for the use of fossil fuels to be less than 50% of the global energy demand by the year 2050.

The DNV report [94] predicts energy supply flexibility and energy storage as two of the most important parts of the energy transition to zero net emission. The main flexibility comes from power production systems. The most flexible systems are thermal and hydroelectric power plants. However, that flexibility is not enough. On the other hand, the flexibility of the energy supply systems comes from energy storage and its performances. Today, most energy is stored within PHS. The forecast for future use of ESSs is on the side of batteries (electrical and electrochemical storage as solar with storage and vehicles-to-grid modules).

Blechinger et al. [98] prioritized using batteries on islands and in remote areas where electricity must be generated from fossil fuel in the absence of electricity generation from RES.

In a few European countries, solar district heating systems have been implemented recently. These systems have seasonal energy storage received from solar fields. The stored energy is distributed as heating for households and as domestic hot water. The entire system is supported by natural gas. Cases in Spain [99] satisfy 26.65% of heat demand. That study suggests that the heat energy seasonal storage is the most polluting part of equipment, and that care should be taken regarding its design and operation. Kang et al. [100] analyzed district heating systems equipped with photovoltaic thermal panels. These systems use energy storage integrated into the unit. Energy storage generally includes boreholes, hot water, and ground storage. Storage is supported by heat pumps. These district heating systems are established in Switzerland, Spain, France, Czech Republic, Denmark, and the Netherlands. Sun et al. [101] proposed a novel solar-driven low-temperature district heating and cooling system that can be used to solve the problem of time mismatch between supply and demand by utilizing centralized unpressured pit TES and distributed ice TES, and to solve the problem of space mismatch between the solar collector field and consumers by extending the solar energy transmission distance cost-effectively. This system uses centralized HS of solar-generated energy. Dan Bauer et al. [102] analyzed small solar district heating systems in Poland, Spain, and Germany. These systems use heat pumps between solar panels and HS tanks of hot water as seasonal storage. In those cases, a very well thermally insulated hot water storage tank with operating temperatures ranging from 10 °C to 90 °C is needed for low heat losses, and unlimited dis(charging) power and high storage capacity are needed. Gjoka et al. [103] reviewed the fifth generation of district heating. Currently developed district heating systems that use renewables are the fourth and fifth generation of district heating systems. The fourth generation presents centralized solar or photovoltaic district heating with heat pumps. In addition, the fifth generation of district heating comprises decentralized systems of the fourth generation with simultaneous bidirectional heating, cooling, and energy exchange. Energy storage is decentralized and is connected to seasonal central storage. Everything should be controlled by the control system in conjunction with data analysis.

4.3. Regulations and Costs

In practice, many countries try to implement energy storage in their communities. Müller et al. [104] analyzed the situation of electricity storage in Germany and West Australia. They found that Germany has the one of the highest percentages of taxes of the total price of electricity distributed to households (53.3%). An analogous situation exists in Denmark where the tax percentage is 58.5%. On the other hand, West Australia has the highest prices for network cost. These high additional costs to the basic price of produced electricity make electricity storage (batteries) an incredibly attractive option. Germany and Sweden support individual residential electricity storage. Approximately 34,000 residential energy storage units were installed in Germany between 2013 and 2016.

Moreover, Koirala et al. [50] explained the complexity of the sociotechnical system for energy storage and distribution through three generalized sides: external environment, actor networks, and physical systems. The external environment includes government, legislation, regulation, national energy markets, National Grid, dominant technologies, institutions, and intermediaries. Actor networks are considered households, communities, housing corporations, energy suppliers, aggregators, system operators, responsible parties, local market operators, technology suppliers, and municipalities. The physical system comprises distributed energy resources, energy storage technologies, energy management systems, local energy exchange platforms, physical and communication networks, and buildings.

Müller et al. [104] compared two different systems where households have their storage system and PV, and prosumers share the common storage system. They found that the first is less affected by the grid regulations as an advantage, and the high-cost investment is a disadvantage. The second system with common electricity storage sharing benefits from the reduction in investment costs, and the fact that the system can be used by other consumers (not prosumers), so the quality of electricity is better and the price of generated electricity decreases. The disadvantages of the second option are the influence of the grid regulations and the need for cooperation with the local distribution network company.

According to Müller et al. [45], if policymakers do not make regulatory changes, shared electricity storage will remain a niche for new housing developments that can set up holistic models based on the ownership of the grid connecting the households. However, if adjustments are made to remove the barriers to sharing over the public network, the models could be promising. In addition to removing tax burdens, policymakers must clarify the regulatory framework. A comprehensive framework that allows for a clear business case would aid in increasing investments in energy storage.

In districts with high grid-related taxes and fees, pilot projects of shared storage systems are now attempting to establish profitable business models within large apartment buildings and/or new housing developments, where the last meters of the grid can be realized in private possession, and thus most grid fees and taxes do not apply. In addition, by establishing a microgrid, new housing developments can plan a comprehensive energy supply that includes electricity storage. Therefore, policymakers should consider adjusting taxes and fees to make community electricity storage viable. Now, projects that use the public grid simulate rather than fully implement novel business models. Greater flexibility and lower fees would undoubtedly aid in the spread of electricity storage systems.

Furthermore, more emphasis should be placed on the control of the distribution network. Access to the distribution network for all parties is critical for transparent and efficient markets. Policymakers should consider options for transforming Distribution Network Operators (DNOs) into active facilitators of community energy solutions. In any case, all policies influencing the model's feasibility must be carefully considered, as policies favoring either will shape the energy system for decades to come [104].

Ownership is important for energy storage facilities. The ESA [105] suggested principles for the ownership of energy storage. All stakeholders, including vertically integrated and restructured utilities, customers, competitive suppliers, and other third parties, should be able to own energy storage. Markets and regulations should strive to maximize the value of energy storage by removing the barriers that prevent storage from providing all the services that it is technically capable of providing. Furthermore, energy storage technologies are a distinct asset class. To recognize and enable the unique functionalities of energy storage, new and/or updated regulations and policies on asset classification, ownership, and competition are required. In addition, energy storage services should be provided within a framework that encourages competition while not favoring specific ownership models or vendors. In addition, differences in ownership models require special considerations in the design and implementation of BTM energy storage programs.

DNV [94] reported the estimated energy demand by the segment of users. The energy demand for buildings will increase by 24% in 2050 and the estimated energy requirements for buildings will be approximately 148 EJ/year. Most of the new energy demand is for new living spaces (new buildings). The primary energy used in buildings will be electricity, but 51% of heating will also be covered by heat pumps. The same technology will cover heating water within 20% of the total demand for hot water. The estimated total energy demand for transportation in 2050 is about 114 EJ/year. The highest use of fossil fuels is to stay in transportation (45% of the total energy demand), but everything depends on the development and use of batteries. Some transportation segments will be completely electrical, derived from RES, but some will still not be independent due to the fuel type and technology that they use (aviation and maritime).

Kalkbrenner [106] analyzed the two different energy storage ownerships in Germany: residential and community battery storage. He helped improve the understanding of consumer preferences and develop customer-focused business models and policy instruments. According to the findings, the subjective feeling of being independent, autonomous, self-sufficient, energy-secure and in control defines energy independence. The predicted decrease in the cost of lithium-ion batteries will allow for elevated autarky levels. End-users in Germany value control but are willing to give it up to support the grid if they can choose when to do so. According to Kalkbrenner's research [106], consumers are willing to pay a premium of EUR 11,486 up front to own a storage system compared to use rights. Consumer willingness to pay is negative for the payback period: To shorten it by one year, they would be willing to pay EUR 697 per year. Respondents are willing to pay an extra EUR 10,325 for total autarky, EUR 6143 for 75% autarky, and EUR 3627 for 50% autarky, compared to 25% autarky.

4.4. New Technologies and New Solutions

An innovative approach is virtually shared energy storage. Germany is among the leaders in shared energy systems. Virtual energy storage networks are already set up such as Sonnen Community® (Wildpoldsried, Germany), Lichtblick—Schwarm batterie® (Cologne, Germany), and Nextkraftwerke® (Cologne, Germany). Nextkraftwerke® [107] is a company established in Cologne, Germany. It organizes and conducts virtual power plants (VPP). The VPP consists of many small prosumers and consumers connected via a network of energy storage and interconnection between prosumers and consumers in real time. Every unit is connected and controlled using the "Next Box" as the mobile connection of the unit to the system and the owner. The connection system, "Next Box", consists of a PLC (Programmable Logic Controller), Modem (communication link between the remote unit and the control system), and Antenna (amplifies the signal reception and can be located up to 15 m from the Next Box). The company's main job is obtaining live data, analyzing, forecasting, and energy balancing. The small prosumers have wind turbines, geothermal energy use, PV systems, biogas, and hydrogen production (storage).

Lichtblick—Schwarm batterie® [108] make the system of solar packets installed in households. Sonnen Community® [109] is working in many countries worldwide. They use PV to generate electricity and produce devices for the use and distribution of electricity.

The DNV Group [110,111] proposes that vehicle-to-grid (V2G) and vehicle-to-everything (V2X) will be crucial in the transition. These systems can create higher flexibility of the distribution system. V2X technologies include vehicle-to-grid (V2G), vehicle-to-home (V2H), and vehicle-to-building (V2B) systems. These can potentially revolutionize how energy is used and managed in transportation and buildings. V2G is a concept of bidirectional connection of electrical vehicles to take power from the grid and provide power back to the grid. This process requires the use of parked and unutilized electrical vehicles. They will be a power source for the electricity grid during periods of high demand, while instantly returning that power to the same electrical vehicles during periods of low demand. The mechanism of this concept allows the grid to expect energy to be stored in vehicles. This accommodates sudden surges in power requirements, such as when households collectively activate high-powered electrical appliances.

Moh Almihat et al. [112] analyzed the energy management in smart cities. A part of smart cities are energy management systems that include the usage of Artificial Intelligence as IoT and building energy management systems. They control the conversion and storage of generated energy from renewables. Smart cities use prediction techniques such as short-term load forecasting, medium-term load forecasting, long-term load forecasting, long short-term memory, convolutional neural networks, discrete wavelet transforms, and recurrent neural networks.

Based on all the aspects presented and discussed in this work, Figure 5 visually represents the possible interconnection between the facilities for energy generation from RES, different forms of energy distribution, and their conversion into short-term or long-term storage. In this design are incorporated the currently most available technologies for citizens and urban areas. Naturally, this is only one of the possible (generalized) views of the authors. This system can be modified in diverse ways in conjunction with other equipment and possible innovative technologies. In this view, solar panels and PVs are the main equipment for energy generation in urban areas (electricity and heat). Generated heat is distributed as hot water to the residential population. The extra heat energy is used for district heating systems (wintertime) or for electricity generation by the ORC. The ORC uses heat from sources (hot water) to generate electricity. In this process, hot water is cooled and can be returned to the system of solar heat generation. The community can partially use the electricity generated by PVs and the ORC at the moment of generation, but surplus energy must be stored in batteries (a better solution could be the use of equipment for all prosumers and consumers as a common service). One part of the stored surplus electricity (short-term storage) will be used at night and during the bad weather conditions in the next few days. The rest of the produced electricity should be used for long-term storage. The best way is storing chemical energy in the form of hydrogen (but also similar compounds). Hydrogen production is based on electrolysis, using electricity for water decomposition. The produced hydrogen is stored for the winter period when the energy generation is lower, and its demand is higher due to the need for space heating. So, the stored hydrogen can be used in two ways, as fuel for district heating facilities and electricity generation. If electricity generation is in the classical way of using the Rankine cycle, part of the heat in the process can be used as additional heat supply for district heating systems. In eco-cities it is possible to produce biogas and biofuels from plants that grow in the city. Moreover, public transportation and cars should be involved in V2G, V2X, V2H, etc. Many other components can be added to the system shown in Figure 5.

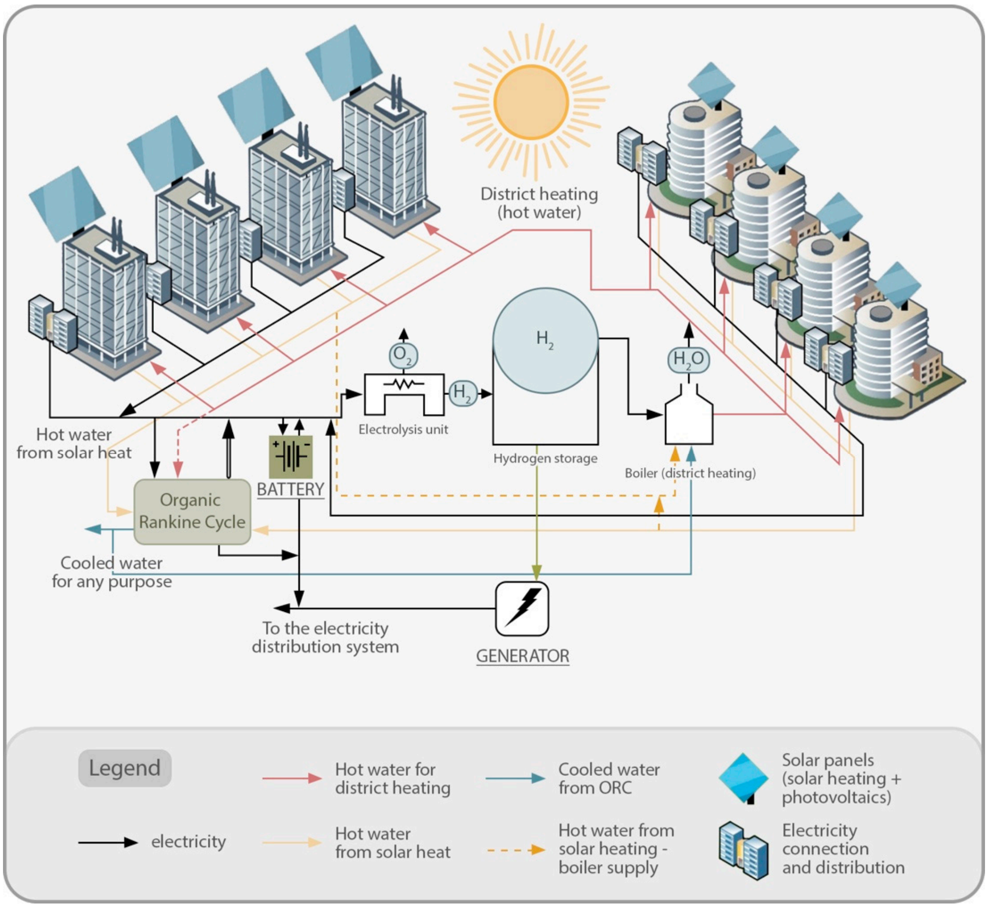

Figure 5. Possible distribution system with energy generation from RES and storage with conversion and distribution.

5. Discussion and Conclusions

The energy transition of urban areas requires substantial local energy production from RES, energy efficiency measures, a high degree of energy flexibility, and the urgent adoption of innovative technologies, policies, and regulations, in an uncertain political and financial environment. This work analyzes how ESSs are developing in urban areas and their possible contribution to mainstreaming PED.

Issues related to the use of ESSs have been identified from different perspectives, encompassing regulatory aspects, technical requirements, environmental protection goals, functionality, and the cost-efficiency of these systems. Researchers seem to agree that batteries, heat, and chemical types of energy storage are the most suitable solutions for energy storage in urban areas, but several concerns still remain. Some of these ESSs, especially batteries, can be extremely dangerous to people and the environment, in terms of accidents and toxicity. Chemical energy storage is the most favorable for long-term energy storage, but regulations for use in urban areas are still unclear. Hydrogen as a clean fuel is used in transport, despite the high cost of the vehicles, and it has great potential to replace natural gas and fuel oil as its main advantage to solve many environmental problems in urban areas. Integrating these energy generation and storage technologies would lower operating costs and reduce environmental and human safety risks by providing a safe and reliable energy supply.

The study found that the lack of knowledge about effective energy storage technologies and solutions, as well as their regulation in each country and at the international level, is the main reason for the low uptake of renewable energy storage systems. Informing stakeholders, including citizens, and providing them with the necessary tools to understand the benefits and advantages of adopting such systems in their cities would allow the definition of new best practices in energy planning, where the PED model has its place as a priority climate change mitigation strategy for the carbon neutrality of urban areas. Another issue is the location and ownership of ESSs. As the cost of standard storage units will decrease, the installation of these ESSs on common property may be a viable solution. However, the use of common units for each prosumer/consumer may require the transfer of ownership to the distribution company in order to avoid conflicts of interest and provide better management of energy systems. Unfortunately, in many countries, there are no laws or regulations on this matter, and where there are, they are made on a case-by-case basis.

The definition of internationally agreed rules and regulations, based on the specificities of each country's energy market and geographical context, would facilitate and encourage the implementation of site-specific ESSs in urban areas, removing barriers and constraints, and promoting integration at the district level, with solutions capable of harnessing the widespread energy production potential at the urban scale.

Modern urban energy system technologies are being developed to find increasingly effective solutions to improve the efficiency of renewable energy generation and distribution systems, while minimizing energy losses from existing equipment and networks. Energy storage can be easily integrated into the energy production and distribution systems to ensure flexibility and avoid shortages. V2G, or V2X in general, include energy storage as a mobile device to balance energy production and demand.

Smart energy management systems play a key role in guiding energy planning in urban areas by providing knowledge and awareness to different stakeholders. There are several controversies, mainly related to the access to information of individual users, who often do not trust the technological innovation of IoT systems, which represents a barrier to the application of such solutions. However, the dissemination of knowledge about the systems adopted and the continuous monitoring of the benefits for citizens and the different stakeholders involved would provide the basis for finding solutions that take into account energy production based on actual demand, optimizing the design of ESSs by reducing security risks, increasing the efficiency of energy storage (e.g., Li-ion battery life), which is useful for promoting an effective energy transition of cities based on energy production exclusively from renewable energy sources.

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Abbreviations

BES	Battery energy storage
BESS	Battery Energy Storage Systems
BTM	Behind-the-meter
CAES	Compressed Air Energy Storage
CBM	Collaborative Business Model
CES	Community energy storage
CSP	Concentrated Solar Power
DES	Distributed Energy Storage
DNO	Distribution Network Operators

DSO	Consumer as the Distribution System Operator
ECB	Electrochemical Battery
ECES	Electrochemical Energy Storage
EE	Electrical Energy
ESA	Energy Storage Association
ESS	Energy Storage System
FTM	Front-of-the-meter
GHG	Greenhouse Gases
HS	Heat Storage
HVAC	Heating, ventilation, air-conditioning, and cooling
ICT	Information and communication technologies
IES	Integrated energy system
IoT	Internet of Things
IRP	Integrated resource plans
LC	Life Cycle
LCC	Life Cycle Cost
LPG	Liquefied petroleum gas
NaS	Sodium Sulfide
NBS	Neighborhood battery system
NPC	Net Present Cost
NPV	Net Present Value
ORC	Organic Rankine Cycle
PBP	Payback Period
PCM	Phase Change Material
PED	Positive Energy Districts
PEM	Polymer Electrolyte Membrane
PHS	Pumped Hydro Storage
PLC	Programmable Logic Controller
PV	Photovoltaic
RES	Renewable Energy Sources
SAT	Storage-as-transmission
SNG	Synthetic Natural Gas
SWOT	Strengths, Weaknesses, Opportunities, and Threats
T& D	Transmission and distribution
TES	Thermal Energy Storage
UPS	Uninterruptible power supply
VPP	Virtual power plant
ZEBRA	Type of rechargeable molten salt battery based on commonly available materials—primarily nickel metal and sodium and chloride.

Appendix A

Table A1. The number of energy storage plants according to the storage type and the amount of energy stored in European countries [20,113].

Location	Number of Plants with Technology	Rated Power [kW]
Greece	4 plants with electromechanical 1 plant ECB and CS	1,429,000 800
Bulgaria	3 plants with electromechanical	1,052,000
Serbia	1 plant with electromechanical	614,000
Bosnia and Herzegovina	1 plant with electromechanical	420,000
Croatia	3 plants with electromechanical	281,740
Slovenia	1 electromechanical 1 plant ECB and CS	185,000 10
Romania	2 plants with electromechanical	53,300

Table A1. *Cont.*

Location	Number of Plants with Technology	Rated Power [kW]
Hungary	1 plant ECB and CS	500
Russia	5 plants with electromechanical 3 plants ECB and CS	2,225,900 3025
Ukraine	3 plants with electromechanical	3,173,000
Slovakia	4 plants with electromechanical	1,017,160
Czechia	4 plants with electromechanical 1 plant flywheel 1 plant ECB and CS	1,145,000 70,000 40
Austria	18 plants with electromechanical 1 plant ECB and CS	4,680,000 64
Italy	19 plants with electromechanical 39 plants ECB and CS 2 plants thermal storage	7,642,700 85,247 5120
Spain	22 plants with electromechanical 17 plants ECB and CS 26 plants thermal storage 1 electrochemical (under construction)	7,997,700 9066 1,131,100 159,300
Belgium	2 plants with electromechanical	1,307,000
Denmark	1 plant with electromechanical 4 plants ECB and CS	6 2865
Finland	2 plants ECB and CS	3200
France	12 plants with electromechanical 13 plants ECB and CS 2 plants thermal storage	5,894,100 14,702 21,000
Germany	31 plants with electromechanical 63 plants ECB and CS 1 plant thermal-storage 3 Chemical storage (under construction)	6,978,840 295,344 1500 250,000
Ireland	3 plants with electromechanical 5 plants ECB and CS 1 plant thermal-storage 2 electrochemical (under construction)	293,820 1547 4560 200,000
Lithuania	1 plant with electromechanical	900,000
Luxembourg	1 plant with electromechanical	1,096,000
Netherlands	2 plants with electromechanical 24 plants ECB and CS	6000 22,090
Poland	5 plants with electromechanical	1,654,800
Portugal	12 plants with electromechanical 2 plants ECB and CS	3,546,600 6005
Sweden	1 plant ECB and CS 1 plant thermal-storage	75 10,000
Switzerland	16 plants with electromechanical 7 plants ECB and CS	6,372,000 2085
United Kingdom	6 plants with electromechanical 29 plants ECB and CS 3 plants thermal storage	3,558,000 47,088 6750

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